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Devoted to All Branches of Optics

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MAY-NOVEMBER 1919

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This Journal is the official organ of the Optical Society of America. It was founded to redeem the constitutional pledges of the society to promote the spirit of coöperation among workers in all branches of optics and coördinate the results of their labors.

To that end it publishes:

1) Original articles;
2) Short abstracts of articles of interest which have appeared in other journals;
3) Abstracts of patents;
4) The proceedings of the Optical Society of America and notes on the activities of local sections.

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Journal

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A CHART METHOD OF TESTING PHOTOGRAPHIC LENSES[1]

By L. E. Jewell

In the testing of lenses by means of photographs of "test charts," it has been customary to use either letters, or simple geometrical figures, or a combination of both, placed upon the chart in such manner as to show the degree of sharpness of definition given by the lens, not only in the direction of the axis of the lens, but also at various angles from this axis.

Upon examination of the photographs the sharpness of the images of the figures on the chart gives a means of judging the definition of the image-forming qualities of the lens. Also the figures upon the chart are usually arranged so as to show the amount of distortion produced by the lens, or the degree of departure from the rectilinear reproduction of horizontal and vertical straight lines, at various angles.

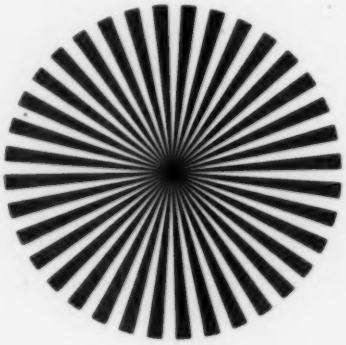
Figures of this kind will, upon an examination of photographs taken of them, give an indication of the sharpness of the images produced by a lens, but not to a much greater degree of accuracy than photographs of any other suitable objects in a plane, such as buildings, etc.

[1] Communication No. 77 from the Research Laboratory, Eastman Kodak Company.

A few years ago Dr. P. G. Nutting, when at the head of the Physics Department of the Research Laboratory at Kodak Park, had constructed an elaborate series of figures, designed to give greater sensitiveness and accuracy to tests of this kind.

The author made a series of photographic experiments with these figures to determine the relative value of the different test figures, also the relative size and distance of the figures from the lens, which would give the best results.

FIG. 1.



After trying the different test figures which had been made for Dr. Nutting, the sector chart was selected, shown in Fig. 1, as containing practically all of the good features of the other charts, and some not possessed by the others, and also being much more simple and satisfactory in every way. Also this form of test figure is influenced by the various aberrations of a lens in a more simple and direct manner than any other, and the results given by it are more easily interpreted.

This test figure can also be made more accurately and easily than any of the others. In photographs taken of charts, in which this sector figure is used, when the distance and size of the figure is properly proportioned to the focal lengths of the lenses used, the radial lines in the central position of the figure will be so close together as not to be separately distinguished by the eye. Also the distance apart and width of the lines vary directly with the distance from the center of the figure.

Instead of determining the definition by a visual examination of the details of the photographic images, it was found possible, when using the

chart, to determine it in a more satisfactory manner by an examination of the general appearance of the sector figures.

In order to understand better the principles involved, suppose we consider the case of a grating consisting of a series of black and white lines of equal width. Furthermore to make the theoretical case conform closely with the actual conditions to be found in practice, we will suppose the white lines to be of the brightness of the surface of good quality white photographic paper, and the black lines to be of the blackness to be found in the blacks obtainable when such paper is exposed to light and developed. The blacks in this case will reflect from four to five per cent as much light as the white surface of the paper. A grating such as that mentioned or any desired variation of it may be prepared photographically. Suppose we photograph this grating under two extreme conditions: (a) in which upon a close examination of the resultant negative by the eye, the photographic image of the grating is completely resolved, the black and white lines being perfectly distinct, and under a second condition (b) in which the photographic image of the grating upon close examination by the eye is found to be unresolved, the black and white lines being completely blended and indistinguishable.

Now place the photographs at such a distance that in the first case (a) the individual lines in the photograph of the grating cannot be visually resolved. The eye when placed at this distance will be unable to detect any difference in the two photographs taken under these two conditions, except perhaps, some difference in brightness, no difference so far as detail is concerned will be observed.

Now suppose we take a series of photographs with different exposure times, under each of these conditions ("a" and "b"). The series of photographs taken under the condition (a) will, when examined in the manner specified, be found to resemble each other, although the exposure times have differed widely from an exposure just sufficient to render the white lines of the original fairly dark, in the negatives, to an exposure much greater, but insufficient to cause trouble from halation, or the spread to the image through diffusion of light because of the nature of the photographic emulsion, or because the black lines of the grating reflect sufficient light to affect the photographic plate with the larger exposures.

In the other case (b) it will be found that the resultant photographs will differ greatly with different exposures. With the shorter exposures the

negatives taken under conditions (b) will be found to look considerably weaker than those taken under conditions (a), until a certain exposure time is reached, when they will be equal in apparent density, and with increasing exposures beyond this point, the negatives taken under conditions (b) will be the denser of the two. These effects are shown in Figs. 2 and 3.

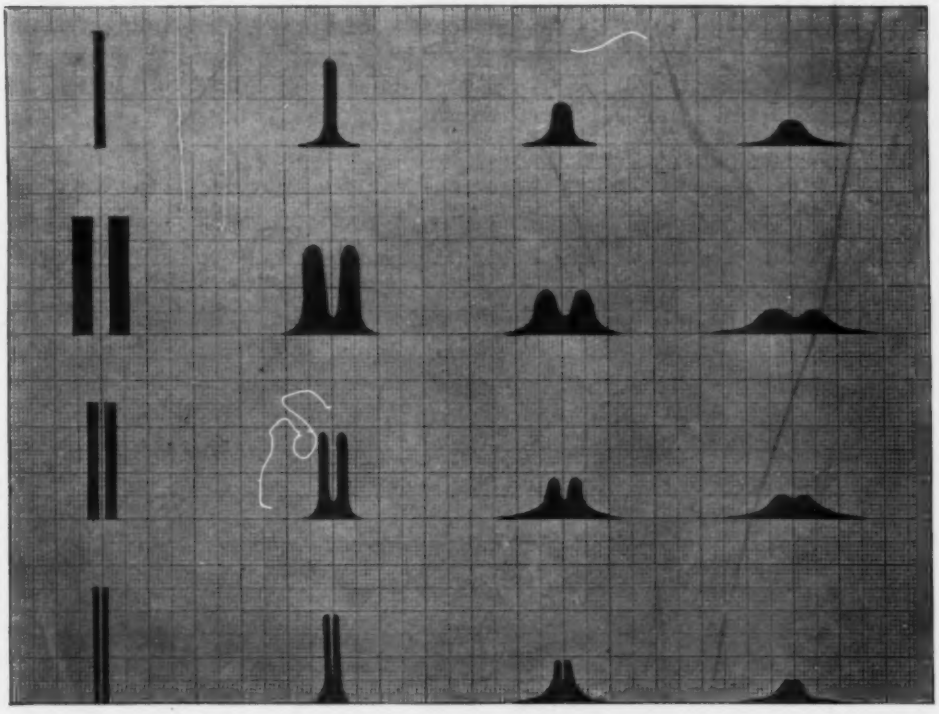


Fig. 2

In Fig. 2 we have a representation of the intensity of a perfect geometrical image of one of the grating elements, and below it three similar images differing, however, in the width of the lines and spaces. To the right of the geometrical representations we have representations of images formed by lenses differing in the quality or extent of their aberrations. Even with a lens of good quality the effects of diffraction and the outstanding aberrations of the lenses will affect the definition unfavorably, and the resulting character and intensity of different portions of the images will be approximately as

represented in the diagrams. Also it can be seen that as the lines are brought closer together, the spaces between the lines tend to fill up and the general form of the image is somewhat less perfect.

The effect of lens aberrations is shown in the other diagrams, and it can easily be seen how the spaces between the lines become more and more filled

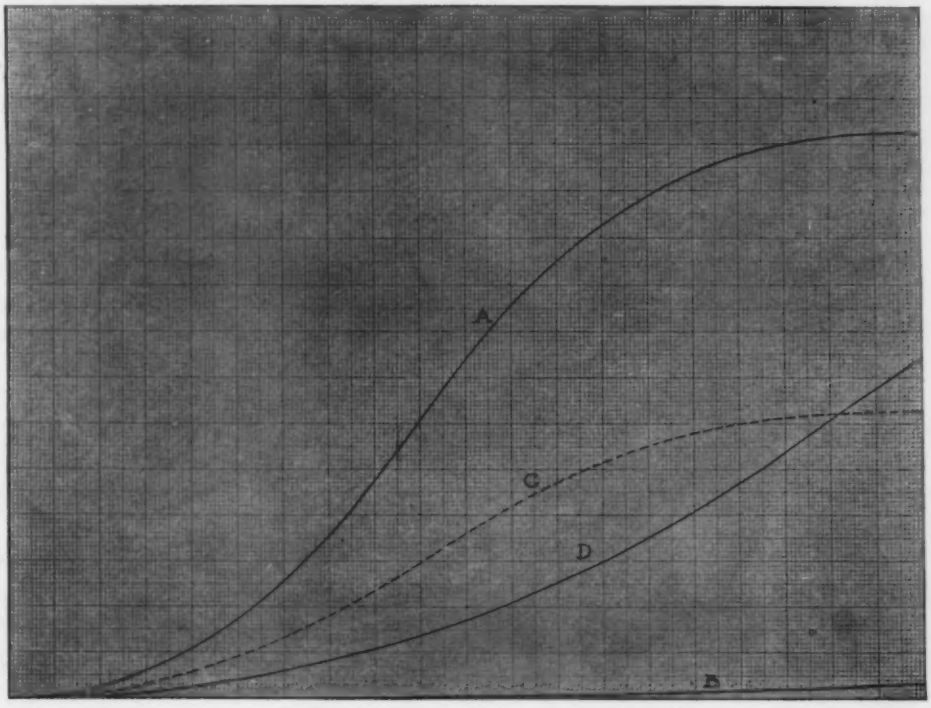


Fig. 3

up and the images less perfect, and in the case of two or more they are seen to tend to be blended together, both as the lens aberrations become greater and as the lines are made narrower and brought closer together. In the sector chart figures, the lines and spaces gradually become narrower and closer together, until they are brought together at a point in the center of the sector figure. It can readily be seen how the distinction between the lines and spaces become obliterated, and the separate elements indis-

tinguishable as the lens aberrations become greater and the lines closer together and narrower.

In Fig. 3 are shown the effect of different exposure times in photographing either the theoretical grating we have been considering, or the sector chart with lenses of different quality.

In the curve "A" is represented the increase in density of the negative image of one of the white spaces, and in the curve "B" the increase in density of the negative images of the black lines of the grating as the exposure is increased when the photographs are taken under condition (a).

In the curve "C" we have represented the apparent density or intensity of the negative where the distance is too great for the images of the individual lines to be resolved by the eye. The apparent density should be the mean of that represented by curves A and B.

If a series of negatives with differing exposures are taken under conditions (b) the resulting densities will vary as represented in curve D, and as the lines are completely unresolved the apparent density will be the same regardless of the distance at which they are viewed. If we compare a set of such negatives with those taken under conditions (a), viewing them as we viewed the others, they will be apparently less dense than those taken under condition (a) up to a certain exposure value, but thereafter they will become denser, soon after this exposure value is reached, the light reflected from the dark areas becomes troublesome also, and it is evident that the point of useful exposure has been passed.

With a lens having aberrations and showing a consequent lack of resolution such as is represented in Fig. 2, the photographic effect will be such that the apparent densities will be represented by a curve somewhere between that of C and D of Fig. 3. Complete resolution will be represented by the curve C and complete lack of resolution by curve D.

Both the partial and the complete lack of resolution of the individual lines or "breaking of the image" will, in the case of the sector chart figures, begin at the center of the figure, and extend outwardly as the effect of the aberrations increase, so that the blurring or "breaking" of the image, caused by imperfections of the lens, spreads from the center outwards to an extent depending upon the degree of imperfection of the lens, and is made easily evident to the eye without the necessity of using a magnifier to examine the images. Also not only the amount of the image forming imperfections of a lens, but their various peculiarities of form, are shown by the characteristic

appearance of the photographic images of the sector figure centers. A photograph of the sector chart showing the characteristic appearances of such photographs is shown in Fig. 4.

When the image formed in the axis of a lens is examined the chief imperfections to be noticed are chromatic aberration, spherical aberration,

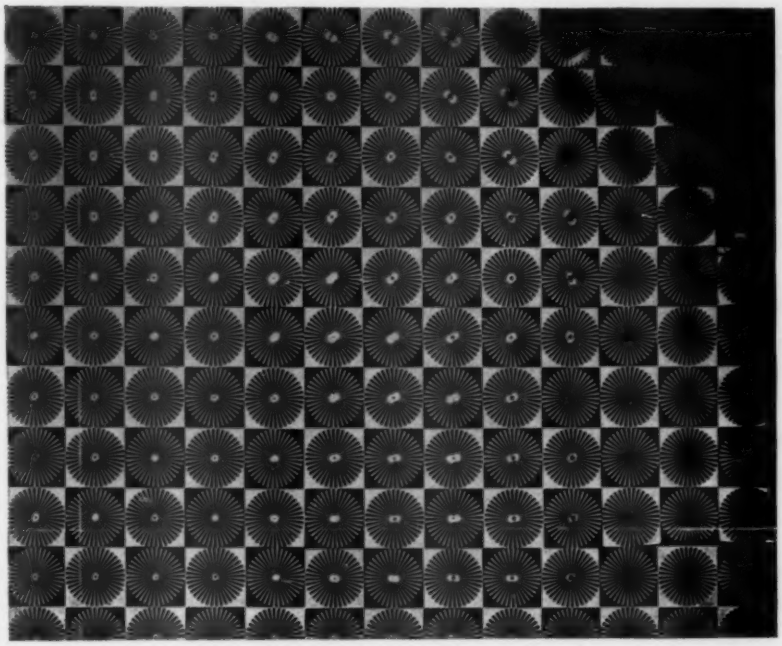


Fig. 4

and imperfection of the image due to glass defects, or defects in the figure of the lens surfaces, and imperfect adjustment of the different elements of the lens.

ASTIGMATISM

The most characteristic of these lens aberrations is astigmatism. It is caused by a dissymmetry in the angles of incidence and emergence to the surface of the lens which the light from an object makes as it passes through the lens, if the direction of the source of light is inclined to the axis of the lens.

The most evident effect of astigmatism is that, with a point source of light, the image tends to concentrate at two foci along the beam of light instead of at a single focus.

With most photographic lenses, the image at the focus nearest the lens tends to be drawn out along a radial line passing through the lens axis. This is known as the secondary image. At the other focus farthest from the lens the image tends to be drawn out tangentially and perpendicular to the other image. This is known as the primary image.

With a lens in which astigmatism is one of the principal aberrations the distance between these two foci or difference in focus between the primary and secondary images, becomes greater as the inclination of the lens axis becomes greater, until it reaches a maximum, when it becomes smaller, until it reaches a minimum known as the node, after which they separate rapidly with the secondary outside of the primary. With some lenses the images at the nodes are nearly as good as in the axis of the lens.

With a test chart in which the sector figures are used, if the primary image is in focus at the surface of the photographic plate, the centers of the sector will be blurred, darkened; and drawn out tangentially, or perpendicularly, to a line joining them with the axis. And if the secondary image be in focus the darkened center will be drawn out radially in the direction of the line joining the image with the axis or center of the chart (when the chart is placed symmetrically with respect to the lens axis). The extent to which these centers are drawn out is dependent upon the amount of the astigmatism of the lens at that angle, and the nearness of the focal plane or photographic plate to one of these astigmatic images.

If the surface of the photographic plate is coincident with the point nearly half way between the primary and secondary foci, the blurred and darkened center of the sector image will be nearly symmetrical. In fact, it will have the general shape that an image of a point source of light placed in the center of the chart would have if focused on the same part of the plate. The amount of blurring, or extent of the breaking of the sector image, will depend upon the character of the lens. The nearer the surface of the plate coincides with the primary or secondary focus the more nearly will the blurred, darkened center of the sector assume the general shape and peculiarities of the primary or secondary image.

If the surface of the plate be outside of the primary or inside of the secondary, the appearance of the sector center will tend to take the general

form of the image of a point source, as it would be formed there. Generally it will be considerably blurred, and the blurring of the sector center will be more extensive but much weaker.

If a node be coincident with the surface of a photographic plate, and a sector figure be situated there, the definition of the sector image may be fully as good as in the axis of the lens.

COMA

Coma is produced by a dissimilarity in the refraction by the outer and inner zones of a lens, similar to spherical aberration, but affecting the rays passing through the lens at an angle inclined to the axis. It is in effect oblique spherical aberration and varies greatly with different types of lenses. A lens in which astigmatism is the most prominent feature is not likely to show a great amount of coma.

At a considerable angle to the lens axis, coma takes the general form of a concentration or head with curved wings or tails, generally separated at an angle of approximately 120°, but varying more or less.

In most lenses it is combined with astigmatism, but in others it is distinctive. One way in which it differs distinctively from astigmatism is in increasing as the angle of inclination from the axis of the lens increases instead of reaching a maximum, then decreasing to a minimum, and then increasing again more rapidly.

Also it causes a different shaped image from that given by astigmatism, being especially distinguished by streamers or tails which may extend to a considerable distance. Coma is also much more affected by the aperture of a lens than astigmatism, being a zonal form of aberration.

One of the consequences of these peculiarities of coma is that the comatic images in general are not so concentrated and are affected by long exposures or bright objects or great contrasts to a much greater extent than the astigmatic images. In distinguishing coma by means of the sector images this is one feature to be particularly noticed. Another is that the shape of the blurred images is more likely to take a roughly square or triangular shape or a general blurring, instead of having a strong tendency to be drawn out in lines radially or tangentially at certain distances from the axis, then contract to smaller dimensions, or disappear and then rapidly become worse, as is the case with astigmatic images.

THE RELATIVE SIZE AND DISTANCE OF THE SECTOR TEST OBJECTS

If the geometrical sector figures were perfectly made it would make little difference what their size was providing they were not so small that the lens aberrations would blur the outer portion of the sectors to such an extent that it would readily be noticeable in a casual examination of the photographs. In practice, however, it is difficult to make drawings and reproduce them photographically in such a manner as to secure charts in which the central portions are entirely satisfactory, unless the defects of the central portions are reduced to a minimum by making the chart very large and reducing it down photographically.

As the sector charts are made, there should be a certain ratio between their size and the distance at which they are placed. This ratio has been found to be about ten to fifteen times the diameter of the sector figures, or even more if the lens aberrations are not large. Also as a test chart or any test object should be further off with a long focus lens than is necessary with one of shorter focus, it is well to have the chart further off and the sector figures larger with a long focus lens.

A chart made up with the sector figures can, however, be used over a considerable range of focal lengths and give satisfactory results. It is desirable to have the chart as far off and the sector figures as large as can conveniently be arranged for. They should be at least twenty or thirty feet away, if possible. If it is necessary to have the chart closer the result will not be so good for long focus lenses, but for lenses of shorter focus it will answer very well.

The best arrangement of sector figures on a chart will depend upon how many of them are available. The best arrangement would be to fill the chart with the figures arranged in parallel rows, both horizontally and vertically, with the center of the chart coincident with the axis of the lens. In practice it may be found impossible or inconvenient to have such a chart. In this case there should be a horizontal row of figures, extending out far enough to give data for the full extent of the field covered by the lens. There should also be a vertical row with other figures so disposed over the chart as to give the most useful results. The area upon which has been placed the sector figures should cover at least one quadrant of the lens field, and lines should be drawn so as to give the distortion as well as the aberrations of the lens image, which will be shown by the appearance of the sector figures.

Another matter to consider is that because of the imperfections of the sector figures near their centers and the fact that the figures are not perfectly black and white, but reflect some light, it is desirable in order to secure the best results to have the chart as evenly illuminated as possible, and if possible to have it illuminated with artificial light in order to have the exposures nearly constant. Perhaps the principal reason for this precaution, however, is that the fainter imperfections of the lens images, which have little to do with the photographic images under ordinary circumstances, will produce a photographic effect if the exposures be much too great, sufficient to darken and blur the images to an extent out of all proportion to their real importance, and give an unfair estimate of the imperfection of a lens, or disguise the details which it is desired to examine. A little care, however, will obviate any trouble due to this cause.

It is also, because of the reasons mentioned, desirable to use a photographic plate giving a considerable degree of contrast, and also to use an exposure and development that will give an increase of contrast greater than would ordinarily be obtained. By so doing the aberration effects are rendered more distinct and can more easily and certainly be examined and their magnitudes estimated. If these details are not attended to the fainter and more diffuse defects of lens images are more likely to be rendered visible, and disguise to a considerable extent the aberrations which we wish to examine.

Research Laboratory
EASTMAN KODAK CO.
Rochester, N. Y.
December 24, 1918

DISPERSION FORMULAS APPLICABLE TO GLASS

BY P. G. NUTTING

While theoretical optics has yielded a number of functions relating refractive index to wave length, none of these dispersion formulas represents observed data with sufficient precision for practical purposes. On the other hand several empirical formulas have been offered which not only fit the data quite well but are of such simple structure as to be useful in technical optics. A comparative study of the formulas available appears desirable at the present time.

For determining the relative merits of the formulas, the data of Gifford (Proc. Roy. Soc., May, 1912) made at 13 wave lengths, 0.4046 to 0.7682,

to six decimal places, has been used. Four typical glasses were selected for study; an ordinary crown, a dense flint, a dense barium crown and a borosilicate flint. First a rough test of all the formulas was made by plotting the data for the ordinary crown by each formula, the variables being so chosen that the formula in question would give a linear function, if the formula were correct. The formulas which stood this test were given the further test of rigid calculation.

The various dispersion functions considered were the following: In each n is refractive index and λ wave length, the quantities a, b, c, etc. are constants different in the different formulas and varying from glass to glass. Alternative forms are given.

(1) Simple Power Series (Cauchy Formula)

$$n^2 = a + b/\lambda^2 + c/\lambda^4 + \text{etc.}$$

(2) Laurent Power Series (Ketteler-Neumann Formula)

$$n^2 = \text{etc.} + c\lambda^2 + d + e/\lambda^2 + f/\lambda^4 + \text{etc.}$$

(3) Resonance Formula, Mechanical Theory (Sellmeier)

$$n^2 = a + \frac{b}{\lambda^2 - \lambda_1^2} + \text{etc.}$$

$$\frac{1}{n^2 - a} = A + B/\lambda^2 \text{ (using two terms only)}$$

$$(n^2 - n_0^2)(\lambda^2 - \lambda_1^2) = \text{const. two terms}$$

(4) Resonance Formula Electromagnetic Theory (Maxwell-Helmholtz-Drude)

$$n^2 = 1 + \frac{a\lambda^2}{\lambda^2 - \lambda_1^2} + \text{etc} \qquad \frac{1}{n^2 - 1} = A + B\lambda^2$$

(5) Rectangular Hyperbola, Index-Wave Length (Hartmann Formula)

$$(n - n_0)(\lambda - \lambda_0) = \text{const.}$$

$$\frac{1}{n - n_0} = A + B\lambda$$

$$\log (n - n_0) + \log (\lambda = \lambda_0) = \text{const.}$$

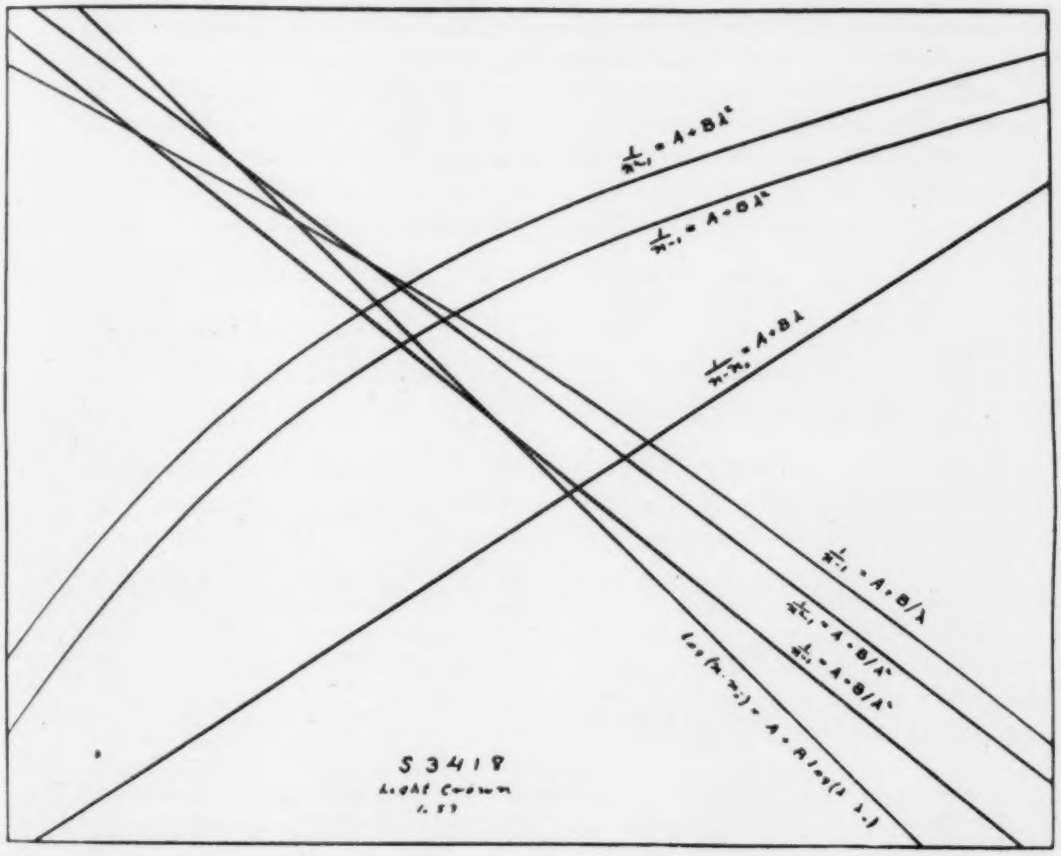
(6) Rectangular Hyperbola, Index-Frequency (n, ι)

$$(n - n_0)\,(\iota - \iota_0) = \text{const.}$$

$$\frac{1}{n - n_0} = A + B/\lambda$$

(7) New Two-Constant Formula

$$\frac{1}{n - 1} = A + B/\lambda^2$$



The figure indicates that formulas 1, 2 and 6 are not of technical interest. The remaining four formulas show agreement with the data to within 2% of the differences involved. Of these, 4 and 7 contain but two constants, while 3 and 5 contain three. Ease of calculation being considered, 7 is simpler than 4, and 5 than 3. Therefore, 5 and 7 have been chosen for the more rigid test. Formula 7 is readily handled by logarithmic calculation but 5 is not, chiefly on account of the ratios of small differences involved. However, the constants of 5 may readily be computed with a machine to the desired precision.

In the following tables are listed the differences in index, *computed-observed*. For computing the three constants of the Hartmann formula (5) Gifford's indices at wave lengths 0.4046, 0.5270 and 0.6563 were used, while for the two constants of formula 7, the values at 0.4341 and 0.5893 were used. Different curves were plotted from data recalculated by formula at at least six wave lengths, and the values tabulated from these curves.

TABLES OF DIFFERENCES. COMPUTED–OBSERVED

	Ordinary Crown S 3418 (1.53)		Dense Barium Crown S 4704 (1.61)	
	Formula 5	Formula 7	Formula 5	Formula 7
0.400	+0.000005	+0.000030	+0.000005	0.000006
0.425	0.000033	5	0.000035	0
0.450	55	0.000005	62	0
0.475	20	2	40	11
0.500	0.000002	0.000003	0.000017	0.000020
0.525	0	8	3	22
0.550	3	7	+0.000011	21
0.575	10	3	15	8
0.600	0.000012	+0.000004	+0.000015	+0.000007
0.625	8	20	10	32
0.650	0	71	6	58
0.675	+0.000008	121	0.000008	84

	Ordinary Dense Flint C 629 (1.61)		Borosilicate Crown S 3338 (1.54)	
	Formula 5	Formula 7	Formula 5	Formula 7
0.400	+0.000018	−0.000404	+0.000017	−0.000077
0.425	−0.000404	103	−0.000039	20
0.450	76	+0.000071	52	+0.000019
0.475	44	132	34	36

0.500	−0.000021	+0.000144	0.000018	+0.000032
0.525	2	122	2	19
0.550	+0.000015	98	+0.000015	6
0.575	26	22	12	0
0.600	+0.000028	−0.000017	−0.000008	+0.000003
0.625	25	62	12	22
0.650	11	103	7	48
0.675	−0.000019	144	+0.000007	71

From these differences it would appear that the two-constant formula (7) represents the data quite as well as the three-constant Hartmann formula, except perhaps in the case of the dense flint glass. Either sufficiently well represents the data to serve all practical needs for interpolation. The Hartmann formula is least satisfactory in the short wave lengths, giving low values in all cases in the region from 0.425 to 0.475. If the curve of errors is determined and corrections applied, either formula will yield results in agreement with data to within a few units in the sixth decimal place. In a later paper, the application of these formulas to the construction of glass tables for even wave lengths will be described.

Pittsburgh, Pa.
April, 1919.

THE MEASUREMENT OF THE INTENSITY OF TRANSMITTED AND REFLECTED LIGHT BY POLARIZATION PHOTOMETERS

By F. E. WRIGHT

In the present paper a brief statement is given of the methods used by the writer during the war period for the measurement of the light transmission of optical glasses and of optical instruments. In the course of the work several attachments to the Koenig-Martens photometer were devised and proved to be satisfactory in practice; a photometer equipped with a calcite cleavage rhomb was also tried out as a substitute for the Koenig-Martens photometer. In the following pages these instruments and the methods for their use are described briefly with special emphasis on those features which are apparently novel.

The Koenig-Martens Hand Photometer. The optical arrangement of this photometer is shown in Fig. 1. Its essential feature is the Wollaston cube, *W*, which consists of two calcite prisms so cut that the optic axis in

each prism is parallel to the end surfaces of the cube, so that, when cemented together along the sloping surfaces, the optic axes in the two prisms are at right angles the one to the other. The effect of the prism is to produce two divergent beams of plane-polarized light polarized at right angles, the first to the second. These are reduced to a common plane of vibration by the analyzer N. The intensity of each beam of light, as observed through the analyzer, is proportional to the square of the cosine of the angle which its

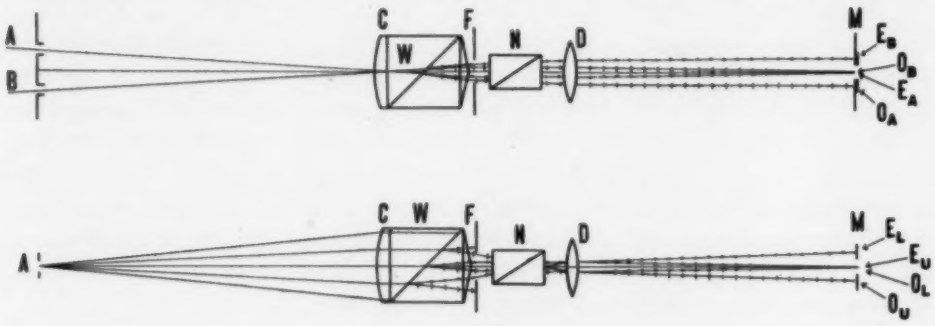


Fig. 1

Optical arrangements of Koenig-Martens photometer. In the upper half of Fig. 1 the paths of the rays from two apertures, A, B, are shown; in the lower half the paths of the rays when only one aperture, A, is employed.

plane of vibration includes with the plane of vibration of the analyzer; at each instant, therefore, the intensity of the one field, I_1 is proportional to $\cos^2\alpha$, that of the other, I_1, to $\cos^2(90°-\alpha) = \sin^2\alpha$; the ratio of the intensities is $\frac{I_1}{I_1} = C.\tan^2\alpha$. The constant C in this equation is the ratio of intensities of the two beams of light emerging from the Wollaston cube. This ratio is approximately equal to unity. An extended series of computations shows that for a Wollaston prism of slope angle 45°, $C = 1.0026$ in case the two end faces are protected by glass slips cemented to the prism with Canada balsam ($n = 1.540$); for the bare Wollaston prism $C = 1.0006$. It is, therefore, permissible in this type of prism to consider that $C = 1$ and

$$\frac{I_1}{I_2} = \tan^2\alpha \tag{1}$$

The error made by this assumption is negligible. In every instrument, however, the validity of this assumption should be tested and the value of C ascertained from the angular position α of the analyzer for which the two

halves of the field are equally illuminated. The values of a, computed from equation (1), for intensity ratios I_1/I_2 from 0.01 to 1.00 are listed in Table I.

TABLE I

In this table are listed the values of a computed from equation (1) for different intensity ratios, I_1/I_2, of the two fields from 0.01 to 1.00.

$\frac{I_1}{I_2}$	a	a	$\frac{I_1}{I_2}$	a	a	$\frac{I_1}{I_2}$	a	a
0.01	5°42.7′	5.71°	0.36	30°57.8′	30.96°	0.71	40°07.1′	40.12°
0.02	8 03.0	8.05	0.37	31 18.7	31.31	0.72	40 18.9	40.32
0.03	9 49.6	9.83	0.38	31 39.1	31.65	0.73	40 30.6	40.51
0.04	11 18.6	11.31	0.39	31 59.1	31.99	0.74	40 42.2	40.70
0.05	12 36.3	12.61	0.40	32 18.7	32.31	0.75	40 53.6	40.89
0.06	13 45.8	13.76	0.41	32 37.9	32.63	0.76	41 04.9	41.08
0.07	14 49.2	14.82	0.42	32 56.7	32.95	0.77	41 16.0	41.27
0.08	15 47.6	15.79	0.43	33 15.3	33.26	0.78	41 27.0	41.45
0.09	16 42.0	16.70	0.44	33 33.4	33.56	0.79	41 37.9	41.63
0.10	17 32.9	17.55	0.45	33 51.3	33.86	0.80	41 48.6	41.81
0.11	18 20.9	18.35	0.46	34 08.8	34.15	0.81	41 59.2	41.99
0.12	19 06.4	19.11	0.47	34 26.0	34.43	0.82	42 09.7	42.16
0.13	19 49.7	19.83	0.48	34 42.9	34.72	0.83	42 20.1	42.34
0.14	20 30.9	20.52	0.49	34 59.5	34.99	0.84	42 30.3	42.51
0.15	21 10.3	21.17	0.50	35 15.8	35.26	0.85	42 40.5	42.68
0.16	21 48.1	21.80	0.51	35 31.9	35.53	0.86	42 50.5	42.84
0.17	22 24.4	22.41	0.52	35 47.7	35.80	0.87	43 00.3	43.01
0.18	22 59.4	22.99	0.53	36 03.3	36.06	0.88	43 10.2	43.17
0.19	23 33.1	23.55	0.54	36 18.6	36.31	0.89	43 19.9	43.33
0.20	24 05.7	24.10	0.55	36 33.7	36.56	0.90	43 29.5	43.49
0.21	24 37.2	24.62	0.56	36 48.6	36.81	0.91	43 39.0	43.65
0.22	25 07.7	25.13	0.57	37 03.1	37.05	0.92	43 48.3	43.81
0.23	25 37.3	25.62	0.58	37 17.5	37.29	0.93	43 57.7	43.96
0.24	26 06.0	26.10	0.59	37 31.7	37.53	0.94	44 06.8	44.11
0.25	26 33.9	26.57	0.60	37 45.6	37.76	0.95	44 15.9	44.27
0.26	27 01.0	27.02	0.61	37 59.4	37.99	0.96	44 24.9	44.42
0.27	27 27.5	27.46	0.62	38 13.0	38.22	0.97	44 33.8	44.56
0.28	27 53.1	27.89	0.63	38 26.4	38.44	0.98	44 42.6	44.71
0.29	28 18.2	28.30	0.64	38 39.6	38.66	0.99	44 51.3	44.86
0.30	28 42.6	28.71	0.65	38 52.6	38.88	1.00	45 00.0	45.00
0.31	29 06.5	29.11	0.66	39 05.4	39.09			
0.32	29 29.8	29.50	0.67	39 18.1	39.30			
0.33	29 52.6	29.88	0.68	39 30.6	39.51			
0.34	30 14.8	30.25	0.69	39 42.9	39.71			
0.35	30 36.6	30.61	0.70	39 55.1	39.92			

In the Koenig-Martens photometer (Fig. 1) the light enters the entrance pupils *A* and *B*; these apertures are in the rear focal plane of the lens *C* cemented to the Wollaston prism *W*; the rays of light pass from the Wollaston prism through the biprism *F*, whence they pass as parallel beams of light through the analyzer *N* and the eyepiece lens *D*, and through the exit pupil at *E*. In case the amount of polarized in a beam of light is to be ascertained, as in measurements of sky polarization, a single entrance pupil is used. The path of the rays for this case are shown in the lower half of Fig. 1.

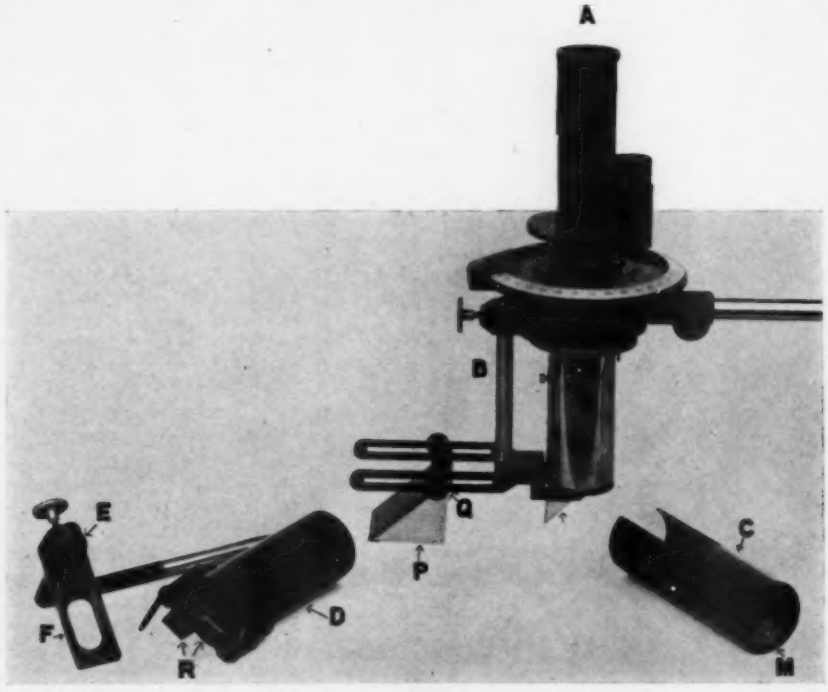


Fig. 2

Photograph of the Koenig-Martens photometer as modified in the instrument-shop of the Geophysical Laboratory. In this figure the following attachments are shown: (1) reflecting prism arrangement *B*; (2) device used in the measurement of the amount of light reflected at approximately vertical incidence from a plane surface, (*D* and *E*); (3) device used in the measurement of the light transmission of an optical instrument, *C*.

In the practical measurement of the light transmission in optical glass and in optical instruments a white uniform source of light is ordinarily obtained by means either of a white diffusing screen of magnesia illuminated

by two electric lamps from the sides, or of a box lined with white paper and illuminated by electric lamps properly placed, or of a cylinder of white drawing paper illuminated at the one end by a strong electric lamp and closed at the other by a piece of white Belgian opal glass with matt ground surfaces.

In order to separate the two apertures (entrance pupils) of the photometer, two reflecting prisms, *P*, *O*, are commonly employed. For this purpose the attachment shown in Fig. 2, *B* was constructed; it is attached directly to the instrument. The large prism *P* slides in the grooves indicated in the figure and can be rotated about the axis at *Q*.

The presence of these prisms decreases the intensity of the one field, and the position of equal intensity of the two halves is no longer at 45° but at a different angle α_0.

Measurement of Absorption of Optical Glass Plate. Let ρ be the amount of light reflected at each boundary surface. Let β be the amount of light transmitted per unit thickness (1 cm.) of plate; then $1-\beta$ is the amount absorbed per unit thickness. For a thickness l the amount of light transmitted is β^l. If multiple internal reflection be taken into account the amount, I, of light transmitted by a plate of thickness l is

$$(2) \qquad I = \beta^l (1-\rho)^2 (1+\beta^2\rho^2+\beta^4\rho^4+---) = \frac{\beta^l (1-\rho)^2}{1-\beta^{2l}\rho^2}$$

From this equation we find

$$(2a) \qquad I\cdot\rho^2\cdot\beta^{4l}+(1-\rho)^2\cdot\beta^l-I=0$$

If in this equation the value of ρ as stated by the Fresnel equation for the intensity of reflected vertically incident light, namely, $\rho = \left(\frac{n-1}{n+1}\right)^2$, in which n is the refractive index of the glass, be substituted, we find

$$(2b) \qquad (n-1)^4\cdot I\cdot\beta^{4l} + 16\,n^2\beta^l - I\cdot(n+1)^4 = 0$$

a quadratic equation in β^l in which n and I are known. The equation is, however, based on the assumption that Fresnel's equation is correct. Experiments with glass plates have proved definitely that the amount of light reflected by a glass surface depends on the materials used in polishing the surface and on its treatment after polishing. Thus, the amount of light reflected by flint glasses can be materially reduced by short exposure of the polished surface to certain solutions. It is advisable, therefore, to eliminate ρ from the equations by measuring the transmission on different thicknesses of the glass plate.

Equation (1) can be written for two different thicknesses l_1 and l_2 of plate

$$\begin{aligned} &\beta^{l_1} \cdot (1 + I_1 \cdot \beta^{l_1}) \cdot \rho^2 - 2\beta^{l_1} \cdot \rho + \beta^{l_1} - I_1 = 0 \\ &\beta^{l_2} \cdot (1 + I_2 \cdot \beta^{l_2}) \cdot \rho^2 - 2\beta^{l_2} \cdot \rho + \beta^{l_2} - I_2 = 0 \end{aligned} \tag{3}$$

From these two equations ρ can be eliminated. In the resulting equation I_1, I_2, l_1, and l_2 are unknown, so that the value β can be ascertained. The resulting equation is, however, so complicated that in general the roots can be obtained only by approximation methods. A direct and simple approximate solution can be obtained by neglecting ρ^2 in equation (1); in this case we find for two transmissions I_1, I_2, measured on thicknesses l_1, l_2.

$$\frac{I_1}{I_2} = \frac{\beta^{l_1}}{\beta^{l_2}} \quad \text{or} \quad \beta = \left(\frac{I_1}{I_2}\right)^{\frac{1}{l_1 - l_2}} \tag{4}$$

The value of β computed from this equation is too low; but it is of the correct order of magnitude.

If internal reflections be neglected, the ratio of the measured transmissions for the two thicknesses is the transmission for the path $l_2 - l_1$. The practical effect of neglecting ρ^2 is therefore to neglect the internal reflections; but these add at most only 0.1 to 0.3 per cent. to the transmitted light. To disregard these in the equations is to obtain too high a transmission and hence too small an absorption. In the case of a thick plate of relatively high absorption this error is not great; but in the case of a thin plate of high transparency the percentage error may be appreciable.

The above relations show that, in case results of greater accuracy are desired, the only feasible method is to measure the amount of light reflected at vertical incidence. The difference between the original intensity and this reflected amount combined with the amount transmitted gives directly the amount absorbed by the plate.

By measuring the intensity ratios for two thicknesses of plate, and by placing each thickness of plate in front, first of the prism set of the photometer and then in front of the second aperture of the photometer, the observer avoids the difficulties arising because of reflection at the boundary surfaces of the glass plate and because of the decreased field intensity ratio resulting from the prism set.

The procedure in measuring the transmission of a plate is briefly:

(1) Ascertain position (a_0) of analyzer for equal intensity of fields when no plate intervenes.

(2) Place plate on flat side (thickness l_1) in front of prism set and read a_1, position of analyzer for equal intensity of fields.

(3) Place plate on end (thickness l_2; $a_2 > a_1$) and read new position of analyzer for equal intensity of the two fields (the angle a_2; $a_2 > a_1$).

(4) Place plate on flat side in front of second aperture of photometer and read a_3 position of analyzer for equal intensity of fields.

Place plate on end and read a_4, $(a_4 < a_3)$ the position of analyzer for equal intensity of the two halves of the field. For each position take 10 readings.

The transmission for a plate of thickness $l_2 - l_1$, is then

$$I = \tan^2 a_2 \cdot \cot^2 a_1 , \qquad (a_2 < a_1) \tag{5}$$

$$I = \tan^2 a_4 \cdot \cot^2 a_3 , \qquad (a_4 < a_3) \tag{6}$$

The transmission β for a plate of unit thickness can be ascertained from the standard equation (4) which may be written

$$\log \beta = \frac{1}{l_2 - l_1} \cdot \log \frac{I_1}{I_2} = \frac{2}{l_2 - l_1} (\log \tan a_2 + \log \cot a_1) \tag{7}$$

In case only one thickness of plate is available the reflection formula of Freanel for vertical incidence may be assumed to be valid, and the equations are

$$\frac{I_1}{I_0} = \tan^2 a_0 \cdot \cot^2 a_2 \cdot \frac{n^2 + 1}{2n} \tag{8}$$

$$\frac{I_1}{I_0} = \tan^2 a_4 \cdot \cot^2 a_0 \cdot \frac{n^2 + 1}{2n} \tag{9}$$

$$\frac{I_1}{I_0} = \tan a_4 \cdot \cot a_2 \cdot \frac{n^2 + 1}{2n} \qquad (a_4 < a_2) \tag{10}$$

In case the amount of light ρ reflected from a single surface has been measured, the value of β can be computed from the quadratic equation (2).

For rapid work the writer prepared a table of $\log \tan^2 a$ for the interval 35° to 45° with increments of 0.01°. This table, however, was not used to any considerable extent because sufficiently exact values were obtained from the graphical plate of Fig. 3 in which the functions $\tan^2 a$ are plotted directly; in this straight line diagram the vertical lines are the angle a_1, the sloping

lines α_1, and the horizontal lines the transmissions, which, when α_1 and α_2 are given, can be read off directly. In this diagram only a limited range of angles is given, but for all optical glasses this range suffices. A second dia-

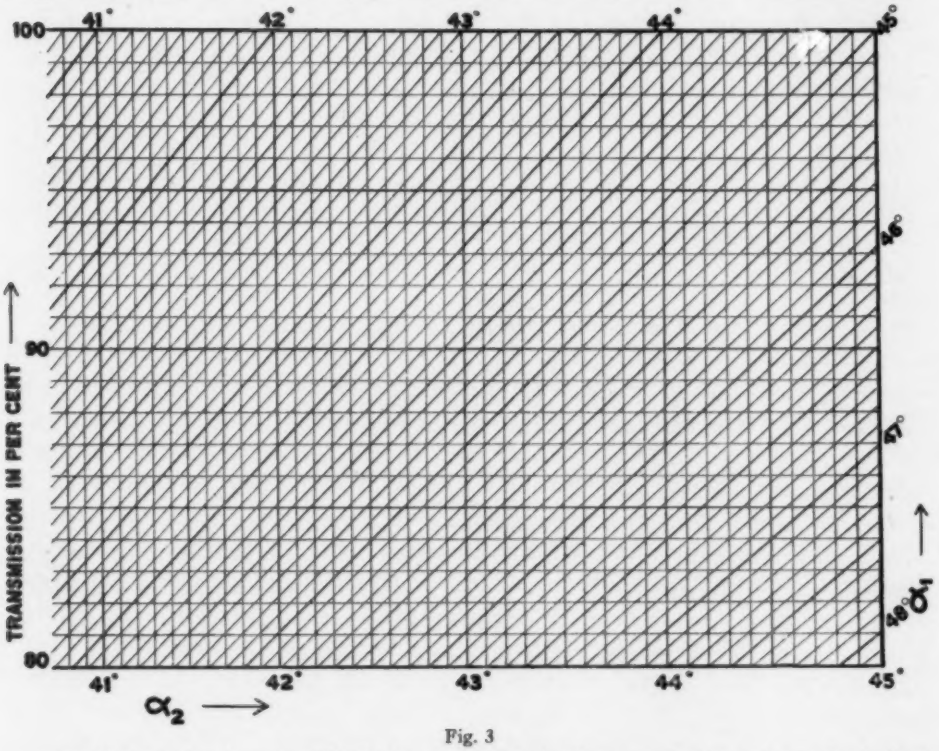


Fig. 3

Graphical solution of equation (5). In this chart the sloping lines represent the angles α_1; the abscissae the angle α_2; and the ordinates the percentage transmissions.

gram of the same character was also prepared giving a much larger range, and was used in transmission measurements of certain optical instruments and of experimental glasses of appreciable absorption.

For the solution of equation (7) the straight line graph was also used and is reproduced in Fig. 4. In this graph the thickness in centimeters $(l_2 - l_1)$ is represented by the vertical lines, the transmission by the sloping lines, and the absorption per centimeter by the horizontal lines. By means of the two diagrams the absorption in per cent. per centimeter of optical glasses can be ascertained directly from the data of measurement.

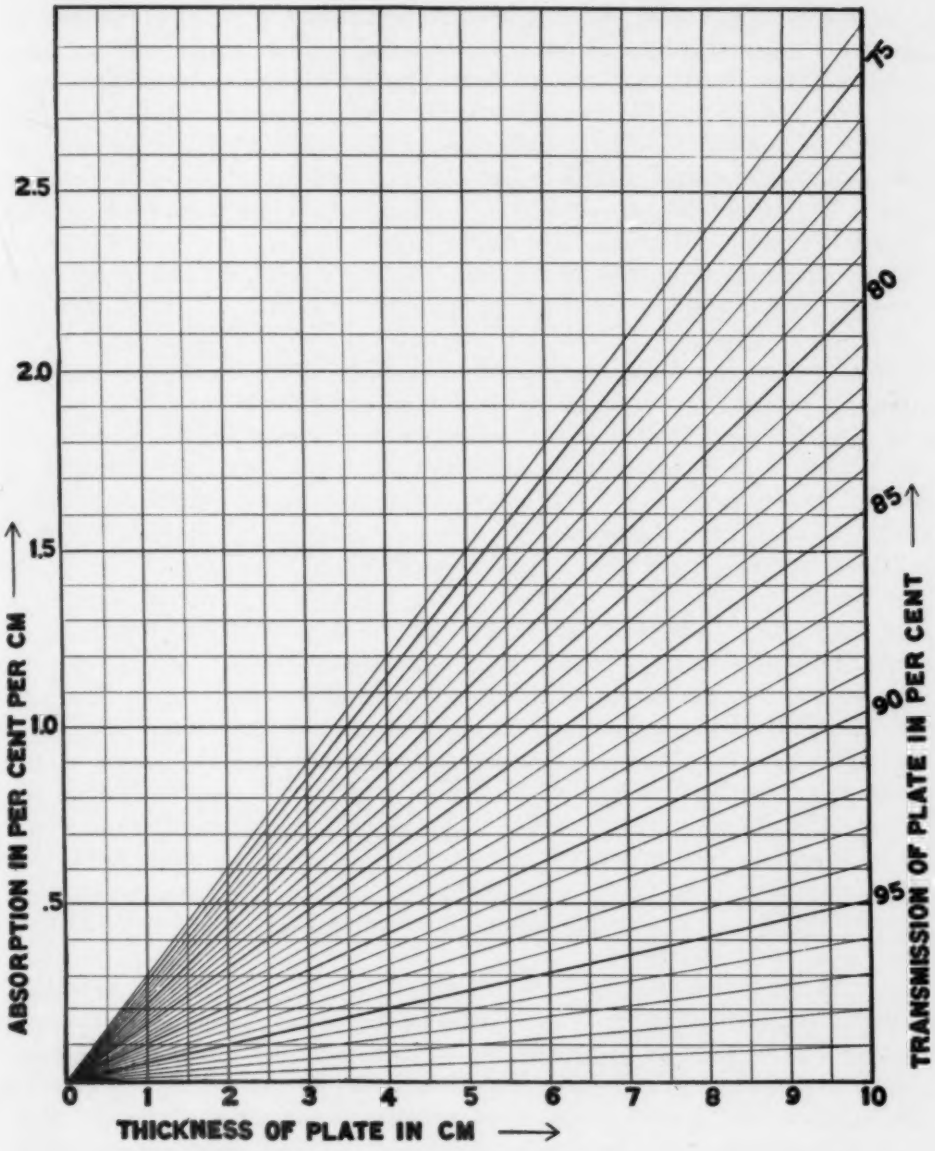


Fig. 4

Graphical solution of equation (7). In this diagram the abscissae represent the thickness of the plate, the ordinates the absorption in per cent. per centimeter, and the sloping lines the percentage transmission of the plate.

Reflection of Light. In order to test the validity of the Fresnel equation for reflected, vertically incident light, and also to ascertain the effect o certain solutions in reducing the amount of light reflected, an attachment was used on the Koenig-Martens photometer which proved satisfactory and simple in operation. The attachment is illustrated in Fig. 2, *D* and *E* It consists of two right-angle prisms *R*, each rotatable about a horizontal. axis. Mounted back of each prism is a lens *A*, the function of which is to image the reflecting surface, held by the mount *D*, Fig. 2, in the image plane of the eyepiece. The cylindrical mounting for the prisms and lenses slips over the end of the Koenig-Martens photometer to such a position that the apertures of the photometer are located at the rear focal plane of the two lenses. This insures the entrance of parallel rays into the prisms. In practice the glass plate is placed on the mount *E* at *F* at such a position that its reflecting surface is seen in the field of view. The light reflected by the plate in this position is not strictly vertical, but it is so nearly so (10° or less) that no appreciable error is made by assuming strict verticality; this is evident from the general Fresnel expression for the intensity of rays of light reflected at different angles of incidence.

In the practical measurement of the intensity of reflected light it is convenient first to balance the fields with the reflecting surface in front of the aperture at the right side of the photometer and then to shift to the left side by rotating the prisms each through 90° and to match the fields again. By this method the first values are checked against the second. It is also advisable to mount the photometer at some distance from the source of uniform light in order that local differences of illumination shall be eliminated. The uniformity of illumination of the two fields should be tested by observing the fields when both prisms are pointing directly to the source of light, and also when they both point at the reflecting surface. By this method the intensity ratio *C* of the two fields under conditions of uniform incident illumination is obtained.

The Measurement of the Transmission of Optical Instruments. For this purpose the attachment of Fig. 2*C* was used. It consists simply of a lens mounted at the end of a cylinder which slips over the end of the Koenig-Martens photometer. The lens is so placed that its rear focal plane falls on the aperture of the photometer, thus insuring the entrance of parallel light into the instrument. The optical instrument whose transmission is to be measured is placed so that its entrance or exit pupil is imaged by the lenses

F (Fig. 2) and *C* (Fig. 1) in the image plane of the eyepiece. It is immaterial whether the exit or the entrance pupil of the optical instrument be used. In the case of telescopes the entrance pupil (objective end) is more convenient to use because it is much larger. The two fields are first balanced with the analyzer at a_1 without the optical instrument in the path; after which the instrument is placed in the path and the fields are again balanced at a_2. The transmission ratio is then

$$I = \frac{I_2}{I_1} = \tan^2 a_2 \cot a_1, \qquad (a_2 < a_1)$$

The transmission can then be read off directly on the graphical plot, Fig. 3.

MEASUREMENT OF SKY POLARIZATION

A Photometer Employing a Calcite Cleavage Rhomb in Place of the Wollaston Prism. Wollaston prisms were not obtainable during the war, and the scheme illustrated in Fig. 5 was tried out tentatively by the writer as a

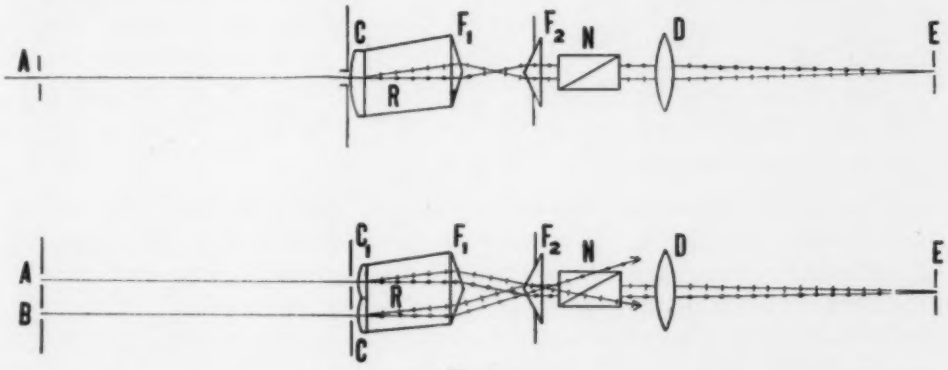


Fig. 5

Optical arrangement of polarization photometer employing a calcite rhomb in place of the Wollaston cube of Fig. 1. In this figure *A*, *B* are entrance pupils; C_1, C_2, lenses situated at focal distance from the entrance pupil; *R*, the cleavage rhomb of calcite, F_1, F_2, two biprisms; *N*, analyzer; *D*, a low power eyepiece; *E*, exit pupil.

possibility. It was found to function satisfactorily but no finished instrument incorporating this arrangement was produced. The scheme offers no special advantages over the Wollaston prism, but it does function well, and in the case of an emergency may be used to advantage.

Geophysical Laboratory
CARNEGIE INSTITUTION OF WASHINGTON
Washington, D. C.
October, 1919

APPARATUS FOR THE TESTING OF BINOCULAR TELESCOPES[1]

By T. TOWNSEND SMITH

The Optical Instruments Section of the Bureau of Standards was called upon during 1917 and 1918 to make check inspections of the binocular telescopes for Army use. One out of every hundred instruments produced by the factories for the Government was sent to the Bureau for test. During the winter of 1917-1918 this testing was not a great task, but during the summer and fall months of 1918 the production mounted rapidly and it became necessary to take care weekly of a relatively large number of instruments, and to give all of them a thorough test.

The tests to be made were the following:

1. Resolution.
2. Field of View.
3. Parallelism of Axes.
4. Magnification.
5. Diameter of Exit Pupil.
6. Accuracy of *mil scale*.
7. Light Transmission.

To make all of these tests without special apparatus would be a very onerous task, and during the summer there was developed at the Bureau of Standards a set of special instruments for the purpose. These instruments are for the most part projection devices, which produce on a screen in front of the observer enlarged images of standard rulings or of scales or stops within the instrument. These large images make it possible to use coarse scales in measuring and render auxiliary telescopes and microscopes for the most part unnecessary. This increases the facility and speed of measurement and at the same time decreases the strain upon the observer. The time consumed in determining the constants of the telescopes is considerably less than that used in tabulating and reporting results, and in packing and shipping the tested glasses. The apparatus is not elaborate; its construction

[1] The apparatus here described was developed in the Optical Instruments Section of the Bureau of Standards during the summer of 1918, and suggestions were contributed by various members of the section. Mr. W. O. Lytle, who was in charge of the binocular testing, made the designs and constructed most of the apparatus. The photometric device and the mil scale projector are the work of Mr. P. S. Brackett, who has also drawn the illustrations for this article.

does not require a great amount of machine work, and the test results are given with an accuracy which is well within the variation allowed by the specifications.

The *limit of resolution* may be determined to the nearest second, except in the case of glasses which show much scattered light, astigmatism, etc., where the limit of resolution is not a definite quantity and the judgment of the observer as to when the test objects may be said to be "resolved" affects the numerical results. The *field of view* may be determined to within one or two minutes, and the *parallelism of the axes* to probably somewhat better than the nearest minute. The *magnification* is read to the nearest tenth, e. g., 6.1, and the *diameter of the exit pupil* is read to tenths of a millimeter, e. g., 4.8 mm. The total lengths of the *mil* and *range scales* are read to the nearest minute. The mean of two or more *transmission* determinations is probably good to about one per cent, e. g., $52 \pm 1\%$.

Inasmuch as the test of the parallelism of the axes is the only one of the tests which is peculiar to a binocular telescope, it is obvious that the apparatus here described may be used for the testing of any small telescope, and part of it is regularly so used. However, the equipment was primarily designed for the testing of six power binocular telescopes, and the apparatus would need to be somewhat modified to make it flexible enough for the more general use.

1. Resolution.

In testing a telescope for resolution the criterion of excellence is the ability of the telescope to distinguish fine detail. For routine testing of this characteristic some fixed test object is highly desirable. Without a test object the question which an inspector has to ask is, "Do I see as clearly as I should?" But when he observes such an object through a telescope the question is more definite, being: "Do I see a particular detail?"

Such an object should be observed under constant conditions. To obtain constant conditions with reference to the test object, an indoor screen of some sort illuminated by artificial light is almost essential. To obtain constant conditions with reference to the observer, the observer should work under the least possible strain and this means that he should use a magnification which is sufficiently great for the defects in resolution to show up plainly. Otherwise the observer is working at or near the limit of resolution for his eye, and his eye is consequently under a severe strain for long periods of time.

The test screen, which was used at first, was composed of a number of groups of fine lines ruled on a silver-backed strip of glass, the spacings of which changed by steps of one second from three to ten seconds. After some experience with the work, a change was made in the test chart by adding other groups of lines at right angles to the original set, so that the test screen has the appearance of Figure 1. The two sets of lines are used in order to eliminate the influence of astigmatism from the readings, and thus make the resolution readings more truly an index of the sharpness of the image which can be obtained with the telescope. This last screen was drawn to a large scale with drawing ink and then reduced photographically.

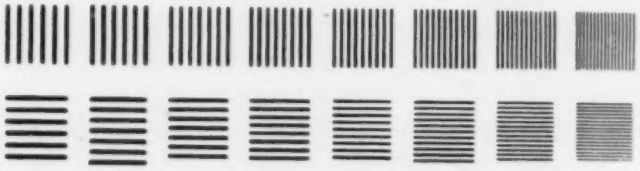


Fig. 1. Screen for Resolution Tests.

This reproduction is a negative to about double the scale used. The mounting for this screen is shown in Fig. 2.

A screen of this type is preferable to one of the type published by Bigourdan,[2] because the bright lines are more readily observed than the lines printed in black on a white background which he proposed.

Way[3] has used a set of dots for a test screen and has published photographs showing the appearance of the field when the telescope is nearly at the limit of resolution.

On the screen which is in use at the Bureau of Standards, a small artificial star likewise appears in the field, and an inspection of this star helps in judging the excellence of the instrument under observation, and in picking out the particular trouble which interferes with the definition, when this is poor.

The resolution screen was mounted as is shown in Fig. 2, in a small projection lantern from which the projection lens was removed. A frosted lamp globe was used for a source of light, a ground glass diffusing screen was placed where the slide would normally come, and the screen was fastened to the bellows with a clip at a distance of three or four inches from the

[2] Comptes Rendus 160:18-21, 1915, and at greater length in Annuaire Bureau des Longs., 1915.
[3] Bulletin No. 41, Topographical Surveys Branch, Department of the Interior, Canada.

ground glass. This screen is viewed through the telescope under test with the aid of a low power auxiliary telescope. In testing the central definition, each barrel of the binocular is in turn adjusted so that its axis passes through the center of the test screen. In testing for oblique definition, the binocular may be pointed to one side.

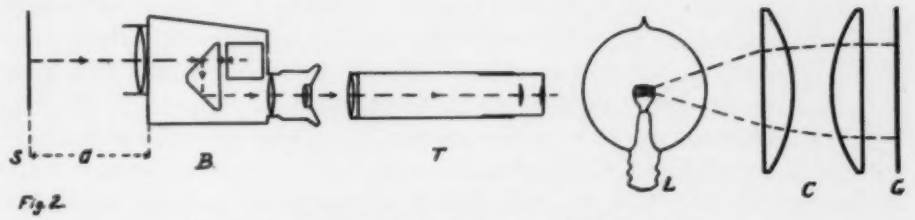


Fig. 2.

Fig. 2. Apparatus for Determining the Limit of Resolution.

Light from the tungsten light (L) inside a lantern housing passes through the condensers (C) and is dispersed by the ground glass (G) so that the test screen (S) is evenly illuminated. This screen (S) is examined through the binocular under test (B) with the aid of an auxiliary telescope of low magnification (T). The distance *a* is about sixty feet. The sketch is not to scale.

Among the principal defects thus observed are:

Scattered Light. From the image of the artificial star streaks of light may appear in almost any direction or in several directions, and it is usually not easy to locate the cause of these.

Astigmatism. A lack of alignment in the prisms will be sufficient to cause an appreciable amount of astigmatism, and the same fault may be caused by giving a slightly cylindrical shape to the objective.

Halos appear in many cases around the luminous lines of the screen, and these have been attributed to the presence of pits in the lenses.

Double Images appear in the field, a defect which in most cases is probably due to a double curvature on one of the surfaces. This defect is very troublesome and curious, the two images behaving in not at all a simple manner as the binocular is adjusted in and out of focus. In some cases the two images appear in sharp focus at the same time, separated by as much as twenty or thirty seconds of arc, or perhaps more, and running into an astigmatic line as the focus is changed. In other cases the two images are not in focus together, but each one is clear and distinct when brought to a focus.

Defects of the sort enumerated above would usually not be distinguished without the aid of an auxiliary telescope. Some of the defects which show

up with the aid of the extra magnification thus furnished will not be appreciable in the normal use of the instrument, and experience and judgment are necessary to enable an observer to decide to what extent the defects which are perceived with the aid of an auxiliary telescope are pronounced enough to affect vision through the instrument. Observations with auxiliary telescopes of various magnifications and check observations with an unaided eye help to surmount this difficulty, if the observer constantly bears in mind that the testing has for its purpose the determination of the probable value of the instrument under average service conditions.

The use of an auxiliary telescope has the advantage just mentioned, and it has the further advantage that the eye is not under strain in making determinations of resolution; the results obtained are consequently more reliable and obtained with less fatigue to the observer. Our experience is that the reliability of unaided eye observations leaves something to be desired, the inspectors at the factory having in a number of cases passed glasses which were palpably poor. This is by no means surprising and does not reflect upon the inspector, for he is asked to perform an almost impossible task when he is constantly straining for the limit of definition in inspecting a large number of telescopes.

A telescope has been considered satisfactory with respect to resolution when the product of magnification and resolution is less than sixty seconds. The best instruments will give a product of forty seconds or under.

With good telescopes the break in resolution is so sharp that one can say with some definiteness and with the personal equation entering in to a very small extent, that one group of lines is resolved and that another group, where the separation is a second less, is clearly not resolved. Lines more widely separated will be clear and distinct. However, with many of the poorer telescopes, in which the defects enumerated above are somewhat prominent, the image of a point or a line will be a composite figure, and two such images will overlap, unless the objects are relatively far apart. In such cases it has seemed best at this Bureau to consider lines resolved only when they are clearly separated from one another, and not when structure is just visible in the image.

2. Field of View.

The angular field of view of a telescope is the angle subtended at the telescope between the two extreme points which may be seen in the field of the telescope. For the accurate determination of this angle a spectrometer

table of some sort is required, but it has been found that the angle can be read to a satisfactory accuracy with the aid of a linear scale which is fixed to the opposite wall of the room.

The scale is graduated in degrees and the field of view is read directly by setting one edge of the field on the zero of the scale, and reading the angle at the other edge. A slight correction needs to be made because the binocular is in focus for an object which is only about fifteen feet (436 cm) distant. This correction is not great and is made on the scale itself, so that the field of view for distant objects is read directly from the scale.

3. Parallelism of Axes.

The apparatus which is used for testing the parallelism of the axes is a projection device. A similar instrument, of which we had a verbal description, is used by the French Government and an instrument working on the same principle has been described by Drysdale in the Proceedings of the Optical Convention for 1905. In all of these the two barrels of the binocular are used simultaneously to project images of two test screens. These images should superpose if the two telescopes have parallel axes, and in other cases their relative positions will indicate the angle between the two axes.

A sketch of the apparatus which is in use at the Bureau of Standards is shown in Fig. 3, which shows a Galilean type of glass in position for testing.

Light from the two screens at F_1 and F_2 passes through the system, being made parallel by the lenses L_1 and L_2 and then being brought to a focus on the ground glass screen G by the large planoconvex lens L_0, which has a diameter of over seven inches (19 cm) and is large enough to take the light from the two barrels of a binocular when spread to their widest. These superposed images, shown at A, are appreciably colored, but are nevertheless clear and distinct.

The binocular is placed for testing, objectives up, upon a plate glass table (not shown in Fig. 3) which is just above the lenses L_1 and L_2, and is there focused for parallel light. The superposed images from the two screens F_1 and F_2 will then appear sharply in focus, having the appearance of the figure at B, which shows the images formed by a pair of binoculars which are well within the tolerance limits.

In the first work with this apparatus the images were projected upon a paper screen in front of L_0, but the images were inconveniently dim, and the mirror M_1 and the plate of ground glass G were added to increase the

brightness of the images. With some screening, the instrument so modified may be used in a moderately well lighted room, provided the lamps used to illuminate the screens at F_1 and F_2 are of sufficient brightness.

Some care needs to be taken in adjusting the position of the mirror M so that the screen G is accurately at the principal focus of the lens L_o, for the readings cannot otherwise be relied upon, and the instrument is rather sensitive with respect to this adjustment. This adjustment can be made by auto-collimation, placing a plane mirror just below L_o and moving M up and down until parallax disappears.

This particular equipment has the advantage that the angle of divergence is measured from the eye side instead of the object side of the instrument, so that, when this apparatus is used, the same tolerance should be allowed for binoculars of different magnifications. It can be readily shown[4] that the angle to which the eye has to accommodate to allow for lack of parallelism between the axes of the binocular is (M-1) times the actual angle between the axes, where M is the magnification. This means that with higher magnifications the eye will be called upon for more *accommodation* unless the angle between the axes is held within narrower limits.

The tolerances under which we have been working are variations of six minutes in the horizontal plane and three minutes in the vertical for the actual angle between the axes for six power glasses, tolerances which were set by the Signal Corps of the Army. The results of our tests would indicate that the instrument makers have no great difficulty in keeping within these limits.

4. Magnification.

In determining the magnification a projection device is used, in which the telescope is used to magnify an image on a screen in front of the observer. The set-up is similar to that used for testing the lack of parallelism between the axes, with two exceptions, namely, (1) only one collimator is used, and (2) the large projecting lens is replaced by a smaller one, having a somewhat smaller focal length (about 70 cm).

At the focus of the collimating lens there is a ground glass screen, on which are ruled with drawing ink two fine, parallel lines. An image of

[4] Let AB be the axis of one telescope and AC the axis of the other, the angle between the two being Q. Now let light come to the binocular along the direction of the axis AB, making thus an angle O with the axis of the second telescope, AC. This light will leave the first telescope still traveling in the direction AB, but will leave the second telescope along a direction A'E, such that the angle CA'E is M times O. The angle DBE, to which the eye has to accommodate itself, is hence (M - 1) O.

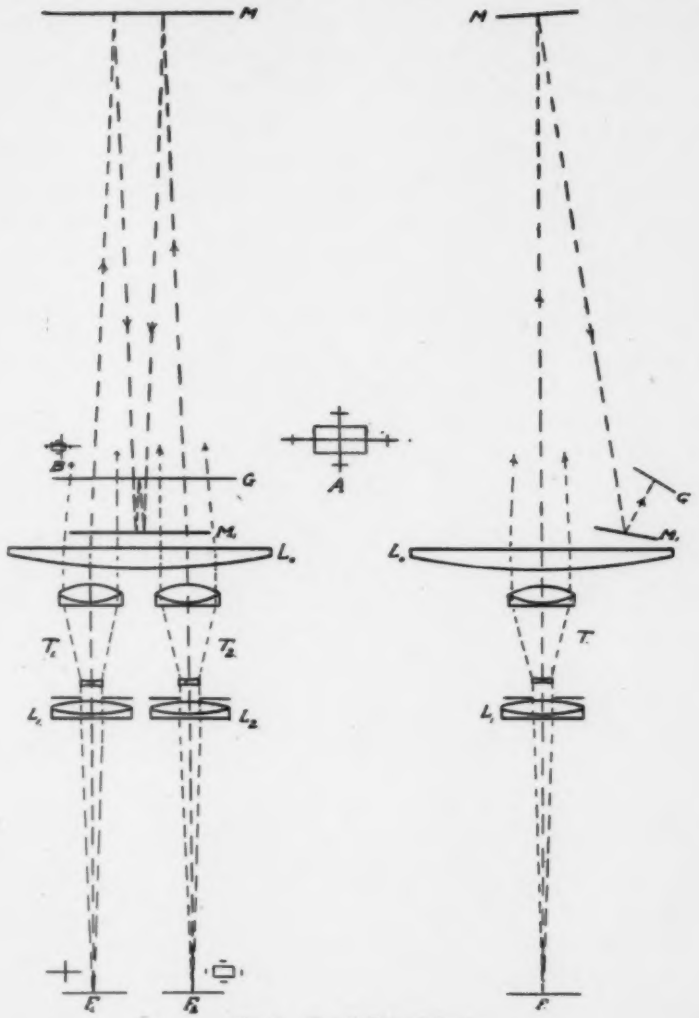


Fig. 3. Parallelism of Axes.

The two parallel collimators L_1 and L_2 bring the light from the strongly illuminated screens F_1 and F_2 to parallelism, after which the light passes through the two barrels T_1 and T_2 of the telescope under test. The light then passes through the single, large, long focus lens L_0, which forms an image of the test screens F_1 and F_2 on the ground glass screen G, after reflection from the mirrors M and M_1. The test screens F_1 and F_2 are of silver backed glass, ruled as is shown at the side. At A is shown the magnified image formed on the ground glass screen G, when the binocular is removed. At B is shown the reduced image formed, when a binocular is inserted which comes inside the tolerance.

The rectangle on the screen F_2 is of such a size that the cross from the screen F_1 will in B appear at the corner of the rectangle if a pair of six power binoculars are out of parallelism by as much as six minutes in the horizontal and three minutes in the vertical. The actual angles subtended at L_2 by the rectangle are $2 \times 5 \times 6 = 60$ minutes and 30 minutes respectively.

these lines is projected upon a second ground glass screen, as in the parallelism apparatus, and this second screen is ruled with equally spaced lines, the distances between which are equal to the distance between the lines of the projected image.

When a telescope is placed in the instrument, objective end down, the distance between the lines in the image increases in proportion to the magnification of the telescope. Consequently the magnification may be read directly on the ground glass scale if this scale be so moved as to bring its zero over one of the lines in the projected and magnified image. The position of the other line with reference to the scale gives the magnification. To facilitate reading, the scale is divided into tenths over a short part of the range and inasmuch as the width of the lines in the image is somewhat less than the distance between these rulings, the magnification can be read to tenths and a little better.

A second pair of lines were ruled on the collimator screen at half the distance apart of the first pair, which extended nearly across the field of the binocular, and check measurements are occasionally made with these narrower lines. No difference has been observed in the readings of magnification between the two pairs of lines.

5. Diameter of Exit Pupil.

The exit pupil is the image formed by the ocular of the objective cell or of some other stop which limits the aperture of the telescope. The size of the exit pupil is of importance because it determines in part the brightness of the image as seen through the telescope. The diameter of the exit pupil together with the magnification determines the *clear aperture* of the telescope, the product of these two quantities giving the diameter of the beam which may pass through the telescope.

In order to determine the diameter of the exit pupil an image of the exit pupil of the instrument is projected by a short focus lens upon a screen which is so placed that the magnification is very accurately ten (see Fig. 4). Consequently, if this image is measured with a scale divided in centimeters and millimeters, the diameter of the exit pupil may be read directly in millimeters and tenths of a millimeter. The edge of the shadow of the limiting stop can hardly be read much more closely.

In order to keep the magnification constant, the projecting lens is fixed at its proper distance from the screen, and the exit pupil is brought to focus

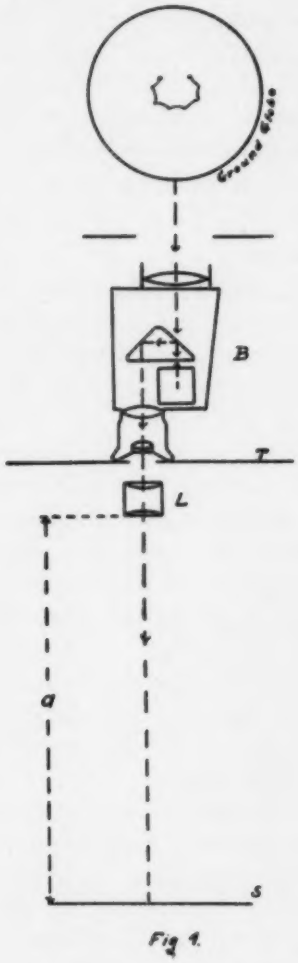


Fig. 4. Diameter of Exit Pupil.

The Binocular (B) is focused for parallel light and is set so that an image of the exit pupil is formed by the lens (L) on the screen (S). The distance *a* is adjusted to give a magnification of 10 and this distance is kept constant. The focusing is done by raising or lowering the platform T on which the binocular rests. The eye piece engages in wooden clips to prevent the binocular from falling during this adjustment as well as to provide a definite setting for the eye piece.

by raising or lowering the binocular. It is usually necessary to change this adjustment only when changing from one type of binocular to another.

This instrument is probably not superior to the microscope and scale device which was originated by Ramsden and is called a dynameter.[5] This projection device cannot, for instance, be in its present form used to locate the position of the pupil with reference to the eye cap, but for the purpose of rapid testing along with the other projection devices it is very convenient and easy to operate.

6. Accuracy of Mil Scale.

In the left eye piece of military binoculars there is set a flat glass disk on which are etched two scales, namely, a horizontal scale of equally-spaced markings which is used for estimating distances, and a vertical scale which is used for range purposes. The horizontal scale is graduated to read thousandths of a radian and is hence called a mil scale, a name which is frequently used to refer to the range and distance scales together.

For the proper use of this scale in observational work it is necessary that the scale and distant objects be in sharp focus at the same time. Consequently the scale should be accurately set at the principal focus of the objective. It is also necessary that the lengths of the divisions should be in a given ratio to the focal length of the object lens, in order that the scale should read the subtended angles truly. For a complete test of the correctness of this scale, the scale of each instrument would need to be tested division by division. This was not attempted, but each instrument was tested for the total lengths of the two scales and for the setting of the scale at the principal focus of the objective.

For this purpose the apparatus which is shown in Fig. 5 was devised, by means of which a much enlarged image of the mil scale is thrown upon a paper screen, which is firmly fastened at its edges to a square piece of plate glass. This screen is marked, for each of the two scales, with a zero line and with two other lines which represent the upper and lower tolerance limits for the scale. The screen is moved about on the table until the zero line on the screen covers the zero line of the image. If then the last line of the projected image lies between the tolerance lines, the mil scale is within the specifications for total length. The total length of the mil and

[5] V. Hofe, Fernoptik, p. 134.
Winkelman, Handbuch der Physik, VI; 457.
Kellner, H. Die Optischen Konstanten des Fernrohrs, Zts. für Inst. Kunde XX, p. 43.

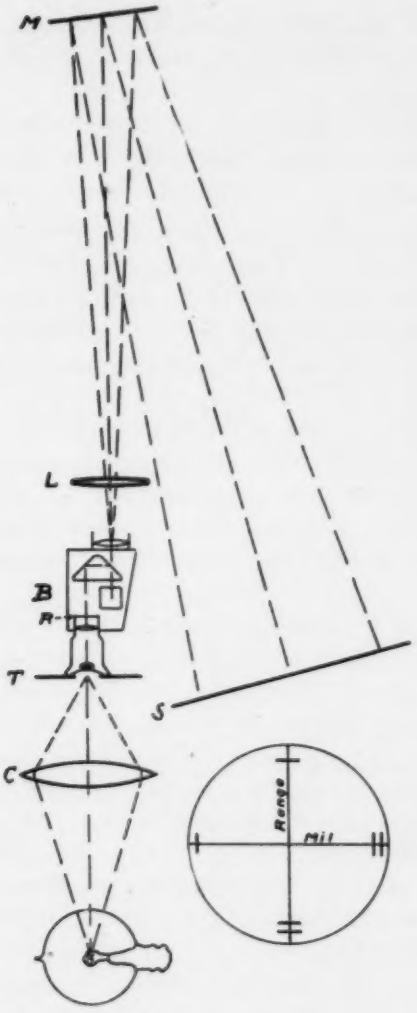


Fig. 5.

Fig. 5. Angles Subtended by Mil and Range Scales.

A condenser lens (C) forms an image of a concentrated filament lamp at the exit pupil of a binocular (B) and provides a strong and nearly uniform illumination for the mil and range scale at R. The objective of the binocular and the simple long focus lens (L) form an image of the mil and range scale on the paper screen at S, after reflection from the mirror at M. The screen (S) is ruled with lines, as shown, within which the outside lines of this image should be situated, if the scale is within the tolerance provided, ±3 minutes.

range scales could be thus tested to within about a minute of arc in a few seconds' time. The tolerance was set at 3′, the angle being a little greater than three degrees.

If the scale in the binocular is not properly placed at the principal focus of the objective, the projected image will not be clearly defined.

7. Transmission.

Of the light energy which enters the objective of a telescope only a portion reaches the eyes. The ratio of the visual light energy which comes to the eye to that which entered the objective is called the transmission. The transmission together with the size of the exit pupil determines the brightness of the image seen through the telescope compared to that seen by the unaided eye.

The transmissions have all been measured on a Marten's[6] Photometer, fitted with a scale calibrated to read the transmission directly. This scale increases markedly the convenience and speed of determining transmissions.

A set of prisms was arranged to do away with the necessity of using a comparison light, and the final arrangement of the apparatus is as shown in figure 6.

By using milk glass and indirect lighting a nearly constant brightness is obtained from a lamp housing, the aperture of which is about 19 cm. The uniformity of the illumination can be tested by comparing different parts of the surface with one another by means of the photometer.

Light from two small regions about A and B passes through the lenses L_1 and L_2 and the two pairs of right-angle prisms to enter the two apertures (A′ and B′) of a Marten's Photometer, whence they pass through the Wollaston Prism (W) and the Nicol (N) to the eye. The light path thus turns two right angles at the totally reflecting prism surfaces, so that the beam, which passes downward through the instrument under test, passes through the photometer horizontally.

The binocular under test is placed on a small platform above L_1 and an image of the exit pupil is brought to a focus at the edge of the bi-prism of the photometer. This image should be formed at the aperture A, but it seems more convenient in adjusting L_1 to place the image at the bi-prism, and a careful test failed to show any appreciable difference in the values obtained.

[6] Phy. Zts. 1:299, 1900.

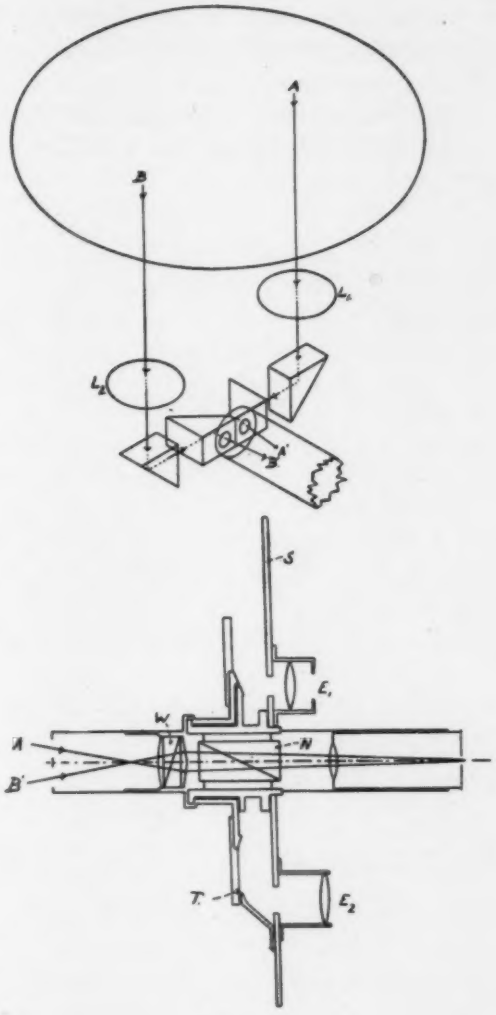


Fig. 6. Transmission Testing.

Auxiliary Prisms used with a Marten's Photometer.

Light from the diffusely illuminated milk glass screen AB passes through the two lenses L_1 and L_2, and the two pairs of prisms to enter the Marten's photometer at A′ and B′. The lenses L_1 and L_2 are simple lenses and the prisms are of the type used in binoculars.

The direct reading scale is at T in the lower figure, which shows the optical train of the Marten's photometer.

This photometric arrangement is very convenient and rapid, inasmuch as it is unnecessary under these circumstances to continually check the zero of the instrument for fear that the relative intensity of source and comparison light may have changed on account of fluctuations in the potential of the lighting system, which will always give trouble unless a set of storage cells can be specially devoted to the work.

Testing Procedure.

The resolution test (1) and the field of view determination (2) are made by an observer from a raised platform, so that he can look over the heads of the other persons in the laboratory. In the case of the resolution determination the line of sight passes through and just under the tops of two doorways. The scale for the field of view determination is set on the opposite wall of the room.

Tests (3) to (6) are made in a corner of the laboratory which is partitioned off and is somewhat less brightly lighted than the open room. The binocular is first placed on the parallelism testing piece (3) and is here focussed to make sure of having the telescopes in focus for distant objects. It is then, without change of adjustment, subjected to the other tests, little manipulation being required beyond the setting of the glass in place and the moving of the scales of the testing instruments so as to cover the distance which is to be measured.

The transmission test (7) is made in another corner of the laboratory which is partitioned off to form a small dark-room.

BUREAU OF STANDARDS
Washington, D. C.
December 31, 1918

THE REFRACTOMETRY AND LISTING OF OPTICAL GLASS

BY P. G. NUTTING

The refractometry and scheme of listing optical glass still in vogue date back to the earlier periods of spectroscopy and lens design, and are not altogether satisfactory. The data supplied is scanty, particularly in the blue and violet regions of the spectrum where the ordinary photographic surface is most sensitive. The indices for the C, D and F lines are unevenly spaced and insufficient for either interpolation or extrapolation by any known dispersion formula for more than a few glasses. The sources used (D and

A' from the sodium and potassium flames, C and F from the hydrogen tube) are convenient enough but the two former are double lines, while the latter are quite broad.

By going over to convenient modern sources (the helium tube and mercury arc) six or eight bright, sharp, well spaced lines are available. The corresponding refractive indices are ample for the determination of the constants of dispersion formulas capable of giving interpolated values to five or six decimal places. The helium tube yields bright narrow lines at 0.4026, 4471, 5016, 5876, 6678 and 7065, while the mercury arc supplies 5461 and with a little gold amalgam 6278. The few other lines present in both spectra are fainter and readily ignored. Both helium and mercury arc tubes are inexpensive. The former is easily operated on a small transformer, the latter on a three or four ampere direct current with simply a rheostat in series.

Gifford in his valuable observations on the uniformity of 35 optical glasses (Proc. Roy. Soc., May, 1912) made determinations at 13 wave lengths, the sources of which were 3 flames (Na, Li and K), 3 vacuum tubes (H, Hg and He) and 3 arcs or sparks (Pb, Fe and Cd), thus necessitating a number of changes of source for each run. The distribution of these lines may be judged from the tables reproduced below.

	Telescope Crown S 3418	Densest Baryta Crown S 4704	Dense Flint C 629	Boro-Silicate Flint S 3338
Wave-lengths	$V=60.6$	$V=55.7$	$V=36.9$	$V=49.9$
A'0.7682. Ka	1.525231	1.603759	1.602071	1.541193
B'0.7066. He	1.526730	1.605638	1.604699	1.543080
0.6708. Li	1.527775	1.606899	1.606572	1.544348
C 0.6563. Ha	1.528248	1.607501	1.607418	1.544942
D 0.5893. Na	1.530848	1.610702	1.612137	1.548146
A 0.5607. Pb	1.532211	1.612434	1.614712	1.549843
0.5461. Hg	1.533016	1.613422	1.616196	1.550829
E 0.5270. Fe	1.534128	1.614824	1.618368	1.552257
F 0.4861. H_β	1.537010	1.618460	1.623982	1.555927
0.4678. Cd_6	1.538584	1.620418	1.627065	1.557896
0.4415. Cd_7	1.541201	1.623677	1.632327	1.561218
G'0.4341. H_γ	1.542020	1.624728	1.634048	1.562291
0.4046. Hg	1.545794	1.629511	1.641979	1.567195

These data by Gifford have been used as a basis in constructing the specimen glass tables below. Both the Hartmann three-constant formula $(n-n_0)(\lambda-\lambda_0) = C$ and a new two-constant formula $(n-1)^{-1} = A + B/\lambda^2$ were used, the indices at wave lengths 4046, 5270 and 6563 being

employed for the former and at 4341 and 5893 for the latter. Differences between observed and indices given by formula affect only the fifth and sixth decimal places except for C 629 in the extreme violet and red. The corrected values given are all certain to within two or three units in the sixth place.

SPECIMEN GLASS TABLE

Wave Length	Light Crown S. 3418	Dense Barium Crown S. 4704	Dense Flint C. 629	Boro-Silicate Flint S. 3338
0.400	1.546473	1.630373	1.643431	1.568081
0.450	1.540307	1.622572	1.630532	1.560083
0.500	1.535946	1.617106	1.621896	1.554568
0.550	1.532785	1.613140	1.615810	1.550566
0.600	1.530380	1.610120	1.611269	1.547564
0.650	1.528460	1.607764	1.607798	1.545204
0.700	1.526875	1.605861	1.605037	1.543283
Dispersion Constants	$^{\circ}P = 51.3$	46.9	29.2	41.3
	$^{\circ\circ}V = 95.5$	88.0	58.2	78.8
Formula Constants	$^{*}A = 1.92985$	1.68107	1.70059	1.878775
	$B = 0.0159986$	0.0151457	0.023258	0.0189075
**	$\lambda_0 = 0.1749140$	0.1796057	0.207686	0.1870975
	$n_0 = 1.512236$	1.587826	1.580383	1.525712
	$C = 0.0077075$	0.0093788	0.0121289	0.0090226

$$^{\circ}P = \frac{n_{450} - 1}{n_{400} - n_{500}} \qquad ^{\circ\circ}V = \frac{n_{550} - 1}{n_{500} - n_{600}}$$

$$^{*}\ 1/(n-1) = A + B/\lambda^2 \qquad ^{**}\ (n - n^{\circ})(\lambda - \lambda^{\circ}) = C$$

Corresponding with the older dispersion constant $V = (n_d - 1)(n_f - n_c)$ are given two new ones: P for the principal photographic region 0.400, 0.450, 0.500 and V for the visual region 0.500, 0.550, 0.600. Another possible selection would be for P the region 0.400, 0.500, 0.600 and for V 0.500, 0.600, 0.700—the first range mentioned is rather narrow, the latter probably too broad. The maximum intensity sensibility and the maximum luminosity for white light, for the average normal eye, fall at about 0.555. On the other hand the axial chromatic correction of the average eye centers at about 0.600. The mean wave length of maximum sensibility for the average photographic surface is probably also nearer 0.480 than 0.450. These considerations would indicate that a better choice for the P region may be 0.400, 0.475, 0.550 and for the V region 0.500, 0.575, 0.650.

Pittsburgh, Pa.
April 1, 1919.

POLARIZATION PHOTOMETER PRISMS

By F. E. Wright

For the measurement either of the relative intensities of two illuminated fields, or of the amount of plane polarized light present in a field, direct-reading polarization photometers are widely used and are sensitive and reliable. As double-image, polarizing prism either a cleavage rhomb of calcite or a Wollaston prism cut from calcite is commonly employed. In both these prisms the separation of the two fields results from the exceedingly strong double refraction of calcite; as a result of the large difference in its refractive indices calcite reflects appreciably different amounts of ordinary and extraordinary incident light, and unless this factor be taken into account slight errors may be made. In the following paragraphs the order of magnitude of these errors is considered and means are suggested for overcoming them in the case of the calcite cleavage rhomb.

The Calcite Cleavage Rhomb. Vertically incident, non-polarized light, on entering the calcite, is divided into two waves—an ordinary and an extraordinary—whose planes of polarization are at right angles and whose ray directions are different. If the two fields resulting from these rays are examined with an analyzer, their intensities of illumination are found to change as the analyzer is rotated. Theory and experiment prove that the intensity of each field is proportional to the square of the cosine of the angle included between its polarization plane and that of the analyzer. Since the polarization planes of the two fields are 90° apart, the relative intensities of the two adjacent fields are proportional to the square of the tangent of α or $\frac{I_\epsilon}{I_\omega} = C \tan^2 \alpha$. wherein C is the ratio of the absolute intensities of the two fields. This ratio was first computed by H. Wild[1] in 1863 and found to be 1.026. The ordinary beam because of its high refractive index loses more on reflection than the extraordinary beam. The equations covering this case were derived by Wild from the general equations of Neumann, but they may also be readily deduced from the standard electromagnetic equations for bi-refracting, optically inactive substances. For vertical incidence the intensity of the ordinary emergent wave is $\frac{2n\omega}{\omega^2 + n^2}$, wherein n is the refractive index of the surrounding medium and the ordinary refractive index for

[1] Pogg. Ann. d. Physik u. Chemie 118: 193–240. 1863.

calcite = 1.65850. The intensity of the emergent extraordinary wave for the same conditions is $\frac{2\epsilon' n}{\epsilon'^2_\epsilon - n^2}$, wherein ϵ' = 1.56456 is the refractive index of the extraordinary wave propagated along the given direction, namely, normal to the cleavage rhomb plane. This includes an angle $\phi = 44°36.5'$ with the optic axis and ϵ' is given by the equation $\frac{1}{\epsilon'^2} = \frac{\cos^2}{\omega^2} + \frac{\sin}{\epsilon^2}$ wherein ϵ is the extraordinary refractive index (ϵ = 1.48635) of calcite. In the above expressions for the intensity of the transmitted beam, account is taken of light derived from multiple internal reflections within the calcite plate. From these equations we find, if the intensity of the incident, non-polarized light be unity, the intensity of the extraordinary ray I_ϵ = 0.453588; that of the ordinary ray, I_ω = 0.44240 and the ratio of the two intensities $I_\epsilon : I_\omega$ = 1.0262. Equal intensity of illumination of the two fields is attained at $\tan^2\alpha$ = 1:1.0262 or $\alpha = 44°15.6'$. In case both ends of the calcite rhomb are protected by glass cover slips cemented with Canada balsam (n = 1.540) the relative field intensities are changed appreciably and the ratio becomes $I_\epsilon : I_\omega$ = 1.0026. The effect of the Canada balsam next to the upper and lower surfaces of the cleavage rhomb is, therefore, greatly to reduce the difference in intensities. Fields of equal intensity are obtained by using a cement of a certain refractive index, n, which can be ascertained, by equating the above expressions for intensity, to be $n^2 = \epsilon' \omega$ or n = 1.61085. The improvement gained by means of Canada balsam is so marked that it should be used. In many prisms the optician protects the soft calcite surfaces with thin glass slips cemented with Canada balsam and thus accomplishes two purposes.

The Wollaston Prism. This prism is a cube consisting of two calcite prisms cemented together and so cut that the principal axis in each prism is parallel to the end surface of the cube (Fig. 1). The light enters the cube normal to the optic axis, and passes through the prism as indicated in Fig. 1. At each boundary surface (1, 2, 3, 4), each wave loses a certain amount by reflection; this amount depends on the refractive index, the azimuth of the plane of polarization, and the angle of incidence of the wave normal. The computation of the intensities for each wave for the four boundary surfaces of the cube (two end surfaces and two sloping prism surfaces) is a long process, but the equations which enable the observer to do

this are standard and are given in text books on crystal optics.[1] The results of the computations are listed in Table 1. Two sets of computations were made for a prism of slope angle 45°; in the one set the prism was considered to be protected on both ends by a film of Canada balsam ($n = 1.540$) as is the case when there are cemented to it certain elements of the optical system such as a lens and a biprism; in the second set the light waves are considered

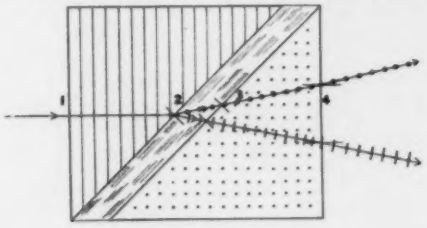


Fig. 1
Diagram illustrating paths of light beams through a Wollaston prism.

to enter and to leave the prism directly into air. In the table the angles which the several refracted and reflected wave normals include with the normals to the four different boundary surfaces of the prism are listed; also the intensities of the waves after passage through each boundary surface. The intensity of the light incident on surface 1 of the prism is considered to be unity. The fifth boundary surface is considered to be that between the Canada balsam film and air.

TABLE I

Intensities and directions of the ordinary and extraordinary light waves after transmission through the several surfaces of the Wollaston prism.

	Ordinary Wave.				Extraordinary Wave.			
Boundary surface No.	Angle of incidence	Angle of refraction	Angle of reflection	Intensity after transmission	Angle of incidence	Angle of refraction	Angle of reflection	Intensity after transmission
			Bare Prism.					
1	0	0	0	0.46927	0	0	0	0.47976
2	45° 00′	49° 35.9′	−45° 00′	.46623	45° 00′	42° 54.9′	−39° 16.5′	.47910
3	42° 54.9	39° 13.0	−42° 54.9	.46520	49° 35.4	52° 14.3	−49° 35.4	.47517
4	5° 47	9° 37.2	−5° 47	.44675	−7° 14.3	−10° 46.1	+7° 14.3	.44702
			Prism Protected with Canada Balsam.					
1	0	0	0	.49931	0	0	0	.49770
2	45° 00′	49° 35.9′	−45° 00′	.49608	45° 00′	42° 54.9′	−39° 16.5′	.49802
3	42° 54.9	39° 13.0	−42° 54.9	.49498	49° 35.4	52° 14.3	−49° 35.4	.49440
4	5° 47	6° 13.8	−5° 47	.49481	−7° 14.3	−6° 58.1	7° 14.3	.49336
5	6° 13.8	9° 37.2	−6° 13.8	.47139	−6° 58.1	−10° 46.1	6° 58.1	.47024

[1] T. Liebsch, Krystallphysik; F. Pockels, Krystalloptik; see also F. E. Wright, Amer. Journ. Sci. (4) 31: 157-211. 1911.

The ratio of intensities of the two emergent waves is: in the bare prism 1.0007; in the protected prism 1.0025. Equal field intensities in the first case are attained at $\alpha = 45° 00.4'$; in the second case at $45°02.1'$. In both instances the differences in intensity are so slight (one quarter of one per cent. at most) that they may be neglected and the square of the tangent of the angle of rotation of the analyzer taken as the ratio of intensities of the two fields. This fact is important, because most readings (as in sky-polarization measurements) are taken with a photometer, such as the Koenig-Martens, which has been adjusted with reference to its positions of total extinction, and the assumption is made that for $\alpha = 45°$ the two fields are of equal intensity. It was to ascertain the order of magnitude of the error thereby introduced that the above computations were carried out. In every instrument of this type, the adjustments may first be made by observing the positions of total extinction of each of the halves of the field ($\alpha = 0°$ and $\alpha = 90°$); once this has been done, settings for equal intensities of field when observing a non-polarized light source should be taken and the departure from 45° ascertained directly, and then introduced as the proportional factor C in the expression for the intensity ratio.

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DETERMINATION OF PLANCK'S CONSTANT "h" BY ELECTRONICATOMIC IMPACT IN METALLIC VAPORS

By PAUL D. FOOTE and F. L. MOHLER

Birge[1] has recently reviewed all determinations of Planck's constant of action h, by various investigators employing seven different methods, and obtained as the most probable mean the value $h = 6.554 \pm 0.002 \times 10^{-27}$ erg. sec. One of the methods considered was that involving the writer's work on ionization and resonance potentials for electrons in metallic vapors. At the present time more data with other elements are available and are accordingly included in this note.

[1] Phys. R. 14, p. 361, 1919.

Two general types of inelastic electronic-atomic impact in metallic vapors are known, one resulting in the complete removal of an electron from the atom and the other in an interorbital shift of an electron within the atom. The kinetic energy of the colliding electron is absorbed by the atom, thus increasing its total energy. Since this condition represents a less stable atomic configuration the atom eventually assumes its normal state, giving up the increased quantity of energy as quanta of radiation of value $h\nu$ where ν is a characteristic frequency. The potential difference through which an electron must be accelerated in order to gain sufficient velocity and energy to ionize an atom upon collision is known as the ionization potential; that required for the second type of inelastic collision is called the resonance potential. The relation between frequency and voltage is of the form $h\nu = e\,V$. For resonance ν represents the frequency of the first line of a principal series; for the alkali metals the principal series of doublets, for the metals of the second group in the periodic table a combination series or principal series of single lines. For ionization of these metallic vapors ν represents the convergence frequency of the same series. The relations have not been definitely established for metals of the other groups, except in a few isolated cases.

Observations on the ionization and resonance potentials of metallic vapors for which these fundamental frequencies are known accordingly afford a means for determining the constant h as expressed by the following equation:

$$h = \frac{e\,V}{C^2\,\nu^1}\,10^8 = \frac{10^{22}}{1.88345}\,\frac{V}{\nu'}$$

where ν^1 denotes wave number, V = volts, $c = 2.9986 \times 10^{10}$ cm/sec and $e = 4.774 \times 10^{-10}$ *e. s. u.*

Table I summarizes data on V obtained in this laboratory, together with the best available determinations of the wave numbers ν^1 i. e. reciprocal of wave lengths in cm in vacuo. These latter are given to a far higher precision than the data on ionization and resonance potentials warrant, but since they represent a consideration of all determinations they are of interest from the purely spectroscopic standpoint.

TABLE I

IONIZATION AND RESONANCE POTENTIALS

Metal	Volts Observed	Wave Number	Reference	Notation
Na	5.13	41444.9	D	$1-5s$
K	4.1	35005.9	D	"
Rb	4.1	33684.8	D	"
Cs	3.9	31406.7	D	"
Zn	9.5	75758.6	a	$1.5S$
Cd	8.92	72532.8	a	"
Hg	10.35	84178.0	a	"
Mg	7.75	61662.8	a	"
Ca	6.01	49304.8	S	"
Na	2.12	16973.3	M	$1.5s - 2p_1$
K	1.55	13042.8	M	"
Rb	1.60	12816.5	M	"
Cs	1.48	11732.3	M	"
Zn	4.10	32500.7	D	$1.5S - 2p_2$
Cd	3.88	30655.2	D	"
Hg	4.9	39409.2	D	"
Mg	2.65	21869.2	D	"
Ca	1.90	15210.1	M	"
Ca	2.85	23652.4	M	$1.5S - 2P$
Tl	1.07	8683.3	D	$1.5s - 2p_1$

D Dunz Tubingen dissertation.
M Meggers Bur. Std. S 312.
a from 1.5 S—2P and 2P (Dunz).
S Saunders.

From the form of the quantum relation the frequencies plotted against the voltages tabulated in Table I should give a straight line, as shown by Fig. 1, the slope of which is proportional to h.

There are several ways of averaging the data to obtain the most probable value of h. Since observations with each metal constitute a determination of h, the arithmetical mean of the separate determinations may be employed. The data may be computed by least squares either on the basis of relative errors in V or absolute errors in V being equally probable. The latter method was used by Birge, but it gives undue weight to the higher voltages. Actually when the voltages are small greater care is taken in the observations, and for this reason we believe either an arithmetical mean or a mean on the basis of relative errors in V being equally probable is more reasonable. The following values are deduced by the three methods of weighting, the probable error of the result being given in each case.

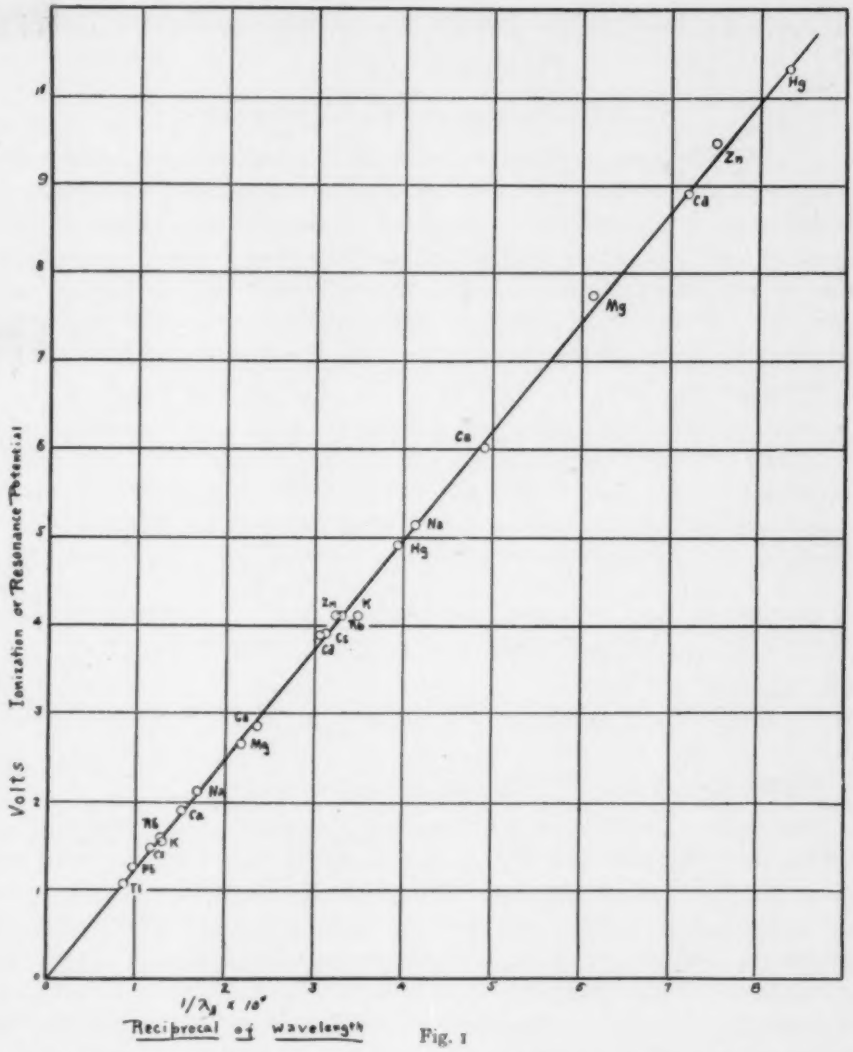

Fig. 1

Arithmetical mean	$h = (6.55 \pm .02) \times 10^{-27}$ erg. sec.
Equally probable relative errors	$h = (6.55 \pm .02) \times 10^{-27}$ erg. sec.
Equally probable absolute errors	$h = (6.56 \pm .02) \times 10^{-27}$ erg. sec.

BUREAU OF STANDARDS
Washington, D. C.
January 15, 1920

CALCIUM AS A DESICCATOR IN OPTICAL INSTRUMENTS

By P. G. NUTTING and C. W. FREDERICK

In certain types of optical instruments serious interference with their use is occasioned by the condensation of internal moisture on the lenses. Such moisture is particularly troublesome in airplane gun sights which are subject to wide variations in both temperature and pressure. Sealing the instrument air tight is a difficult matter and leads to still further troubles. Filling the instrument with dry air serves the purpose only temporarily. Since freezing temperatures are not unusual, the trouble is aggravated by the formation of frost.

Many desiccating agents are available, such as calcium chloride, phosphorus pentoxide and metallic sodium. Anhydrous salts are unsuitable since with moisture they form acids which would be liable to corrode the metal casings. Metallic sodium is too violent and of too short a life. It occurred to one of the authors in witnessing a severe test of an airplane sight, that metallic calcium possesses just about the desired properties and life. It is a thorough desiccator, rather slow in its action and capable of taking care of a very considerable amount of moisture. The hydroxide formed is weakly alkaline and does not corrode metal or glass. It forms a solid shell over the metal core, but is readily penetrated by moisture so that the core continues active. Any salt tending to crack or flake off from the metal may readily be retained by wrapping in blackened gauze.

Some calcium wire about 1.5 mm square prepared at the Westinghouse Research Laboratories was sent to the Eastman Company for trial in a Unit sight. In makers' tests the sights were enclosed in steel jackets and immersed for 20 minutes in brine at far below freezing temperature. An unprotected tube subjected to this treatment would gather a very heavy coating of frost on the lenses, requiring 20 to 30 minutes at room temperature to disappear. The sight containing the calcium, however, showed no trace of frost or moisture.

The official report by the Director of Aircraft Production on subsequent tests at pressures and temperatures equivalent to 25,000 feet altitude gave no condensation on the lenses or the inside of the tube. The Chief of the Instrument Department of the Bureau of Aircraft Production states that

calcium wire is being specified as a desiccator in the permanent specifications for this sight.

The use of calcium as a desiccator is worth consideration for field glasses, telescopes, periscopes and possibly other instruments, particularly where construction is hurried and the internal finish of the tube is not thoroughly dry before assembling. It is quite possible also that certain optical glasses and other materials subjected to corrosion by moisture would be given greater length of life if thus protected.

Pittsburgh, Pa.,
and Rochester, N. Y.
December, 1918

THE CONTRAST SENSIBILITY OF THE EYE AS A FACTOR IN THE RESOLVING POWER OF THE MICROSCOPE

By FRED. E. WRIGHT

The factors on which the resolving power of the microscope depends have been investigated in great detail and are presented in the standard text books on this subject. The effect of different sources of light, both in color and intensity, the rôle played by the condenser in central and in oblique illumination, the need for "critical illumination," the significance of the numerical aperture of the objective, the function of the eyepiece, and the theory of the formation of the image in the microscope are there discussed with adequate emphasis and place the modern microscopist in a position to make the best of his instrument and to push its resolving power to the limit.

There are, however, several factors which depend primarily on the eye as an integral part of the observing system, and which appear not to have received the consideration they merit. We see the details of an object because of contrasts in light and shade or of differences in color, providing the details are sufficiently large to be visible. Three factors have an important bearing on the degree of contrast attained in the image as observed under the microscope, and are especially significant near the limits of the resolving power of the microscope. These factors are: (a) the polarization of diffracted pencils of high angle; (b) the use of a sliding diaphragm in the image plane to exclude all light in the image plane except that from the

object under examination; (c) the variation of the intensity of illumination of the field to obtain the most sensitive conditions for vision.

(a) *The Polarization of Diffracted Pencils of Light.* In the course of a series of tests on microscope objectives the writer was surprised to note the effect of polarized light on the resolution of fine details, such as the markings on the diatom *Amphipleura pellucida*. It was observed that when the plane of polarization (normal to its principal plane, which is considered to be the vibration plane) of the polarizer or of the analyzer was normal to the direction of the lines, these were easily resolved; but that on rotation of the polarizing prism the markings practically disappeared when the plane of polarization was parallel with the lines. This observation led to a series of tests on the character of the polarization of the diffracted pencils of light emerging from series of lines spaced at different intervals. For this purpose a Grayson's test plate was employed on which are ruled sets of parallel lines ranging from 10,000 to 120,000 lines per inch at intervals of 10,000, and mounted in realgar; in addition, well known diatoms, such as *Amphipleura pellucida, Surirella gemma, Frustulia saxonica and Surirella cardinalis*, were used, as well as extremely fine lines scratched on a silvered surface. For most of the tests a Zeiss apochromatic oil immersion objective of 2 mm E. F. and 1.30 N. A. was used in combination with an aplanatic condenser of 1.40 N. A.

The tests proved that when the distances between the lines are of the order of half a wave length of light, *i. e.*, when the interval of the grating is less than 0.000350 mm (70,000 lines to the inch and higher) the first diffracted beam (observed in the rear focal plane of the objective) is appreciably polarized. On a grating of 75,000 lines to the inch (about 3,000 lines to the millimeter, grating interval = 0.000339 mm) the deep red end of the diffraction pencil is practically extinguished when the principal plane (vibration plane) of the polarizing prism is normal to the lines of the grating. On a grating of 90,000 lines to the inch (grating interval = 0.000282 mm) the orange and yellow green are perceptibly reduced under these conditions when the principal plane of the polarizing prism is normal to the lines. On a grating of 100,000 lines (grating interval = 0.000254 mm) the red no longer emerges from the objective; the green and blue diffraction beams are perceptibly decreased on rotating the polarizing prism to the crossed position, whereas, when the plane of vibration of the prism is parallel to the lines, they are easily resolved. On a grating with 110,000 lines to the inch (grating

interval 0.000231 mm), only the blue and green of the diffracted pencil are visible. When the principal plane of the polarizing prism is normal to the lines, the diffraction pencil practically disappears and no lines are detectable in the image; in the parallel position the intensity of the diffraction pencil is greatest and the lines are readily resolved in green-blue light. With a grating having 120,000 lines to the inch (grating interval = 0.000212 mm) only the blue end of the diffraction pencil appears in the aperture of the back lens of the objective. This is practically extinguished when the principal plane of the polarizing prism is perpendicular to the lines. It appears at greatest intensity in the parallel position, but even then the lines in the image cannot be resolved except under the special optimum conditions of observation described in the next section. The relative intensity of illumination of the narrow blue end of the diffraction pencil is so low that an intense source of light is required, and this in turn must be cut down so as to obtain the degree of illumination for which the eye is most sensitive.

Observations similar to the above were made on test diatoms and also on single fine lines scratched on a thinly silvered surface. It was found that there was an appreciable polarization of the diffracted pencil for gratings above 70,000 lines to the inch. In case two diffracted pencils emerged from the objective, as in the case of *Pleurosigma angulatum* (interval about 0.000500 mm), when viewed in oblique illumination, the first pencil showed little if any polarization, while the second order diffraction pencil emerging at the margin of the field was perceptibly polarized.

These observations prove that the diffracted pencils from gratings whose interval is of the order of magnitude of half a wave length of light are appreciably polarized; the plane of maximum polarization is normal to the lines of the grating. Gratings of 100,000 lines to the inch or more are practically not resolved when the plane of polarization of the polarizing prism is parallel with the grating lines; but they are resolvable up to the limit of the numerical aperture of the objective, when the plane of polarization of the polarizing prism is normal to these lines. In making these observations no essential difference was detected in the effects produced by the polarizing prism in either one of the following two positions: (a) below the substage condenser, (b) as a cap prism above the eye-piece. When the polarizing prism (Glan-Thompson type) was introduced between the objective and the eyepiece the general quality of the image was slightly impaired, especially near the

margins of the field. The best place for the polarizing prism is probably below the substage condenser.

In case the polarizing prism be withdrawn and the observations made without it, as is universally the case at the present time, the details are still observable, but the lines appear less contrasted and less sharply defined; the reason for this is that under these conditions an increase of nearly 100 per cent. of the field illumination is super-imposed on the effective illumination; this increase does not, however, contribute to the resolution of the image, because its plane of polarization is parallel to the lines of the grating. The eye is able to detect the lines because of the differences in light intensity of different parts of the image which, as Abbe was the first to show, is a diffraction pattern similar to the object according to the number of diffraction pencils which contribute to the pattern. Experiments by Koenig and others have demonstrated that in a photometric field the least perceptible difference in intensity detectable by the eye is somewhat less than 2 per cent. over a long range of intensities. If now the differences in intensity of the diffraction pattern, as observed through a polarizing prism with its principal plane parallel to the lines, happen to be of the order of magnitude of 4 per cent., the lines are easily detected by the eye; if the polarizing prism be removed, the field illumination is approximately doubled, while the intensity of the diffraction pattern remains unchanged; its relative intensity compared with that of the field is thereby cut in half and the eye is barely able to detect the pattern.

Under ordinary conditions of observation an image whose markings are separated by about half a wave length of light appears in a field flooded with light, which tends to obscure these markings. The marked increase in the ability of the eye to detect details under conditions resulting from the proper use of a polarizing prism is too important a factor to be neglected in critical high-power work on diatoms and similar structures. This remark applies equally well to the photography of such objects. In the case of a second set of fine lines or markings on an object approximately normal to the first, the polarizing prism can increase the visibility of only one set at a time, and to this extent the method is limited in its application and should be so appraised.

(b) *The Use of a Sliding Diaphragm in the Eyepiece.* A second factor is of importance in this connection. For critical work it is essential that the eye should work at a maximum efficiency and that it be free to concentrate

entirely on the particular detail of the image under study. In the microscope as at present used the detail occupies only a part of the field; the eye may receive therefore a large cone of light, only a part of which serves a useful purpose. It is, as it were, flooded with non-essential light which causes retinal fatigue, and this soon decreases the nicety of vision required. It would seem better to exclude this useless light in critical work and to allow only the light from the object itself to enter the pupil. If, on the other hand, the object is very small, experience has proved that it is better to allow part of the illuminated field to remain visible rather than to cut it out entirely. In case the eye observes a small spot of light against a black background, the contrast between light and dark is so great that the minute differences in contrast in the image are less easily observed than in a moderately illuminated field which subtends an angle of 10° or more at the eye. The attainment of the best size of field is best accomplished by means of sliding diaphragms placed in the image plane of the eyepiece. These diaphragms enable the observer to eliminate all light except that which passes the rectangular opening of the stop. The shape of this stop can be changed at will from a square to an elongated parallelogram and all extraneous light eliminated. This type of diaphragm is superior to the iris diaphragm whose opening is always circular, whereas many of the diatoms are elongated and can be better separated from the field by means of the rectangular sliding diaphragm.[1] Practical work with diaphragms of this type has demonstrated its desirability for critical examination of fine structures. An iris diaphragm is much better than no diaphragm and is mechanically easier to fit into the eyepiece.

(c) Still a third factor deserves notice. Experience has shown that the sensitiveness of the eye varies from time to time and also with the conditions of illumination. At normal intensities of illumination such as daylight, a good eye is able to distinguish two points separated by about 1 minute of arc. As the intensity of illumination falls off, the angular separation increases noticeably, so that at twilight illumination points which can just be distinguished are separated by many minutes of arc; at the threshold limit of intensity perception the angular separation of points just resolvable may amount to several degrees. For this reason the use of field glasses which

[1] A diaphragm of this type has been in use for many years by the writer in the study of interference phenomena of small mineral grains in the thin section. See F. E. Wright, Methods of Petrographic Microscope Research. Carnegie Institution of Washington, Publication 158, p. 78. 1911.

magnify and thereby increase the apparent angular separation between distant points enable the observer to resolve objects that otherwise would escape attention. The mariner and the soldier can see better under twilight conditions with a glass than without it, even though the actual light intensity is appreciably lessened by its use.

In high-power microscope work the source of light is generally fixed and its intensity is constant. For the resolution of the finest details it is necessary to illuminate the full aperture of the objective or to use as oblique illumination as possible. Under the conditions for the best observation the intensity of field illumination should be variable within certain limits, in order to attain the particular intensity of illumination for which the eye at the moment is most sensitive. It may not be convenient to cut down the light source; the field intensity may, however, be reduced by means of a neutral tint wedge, or better, by the use of a substage polarizer in conjunction with the polarizing prism. By suitable rotation of the polarizer the intensity of the transmitted light can be reduced at will and the best conditions thereby obtained. Under conditions of extremely oblique illumination it is not possible to obtain total extinction, because of the rotation of the plane of polarization of the waves refracted in the condenser and objective at high angles of incidence.

The value of this procedure was proved when the effort was made to resolve a grating of 120,000 lines to the inch. Under ordinary conditions of illumination the lines could not be seen. With oblique illumination a narrow band of green-blue light was observed at the margin of the rear focal plane of the objective. Resolution was finally effected with the aid of direct sunlight; a small stop was placed at the margin of the lower focal plane of the condenser; the substage mirror was so adjusted that the field appeared illuminated in greenish blue color; an analyzer was used with its principal plane parallel to the lines of the grating; the substage polarizer was inserted and rotated to the position for which the best conditions of illumination were secured. When the field intensity was too bright the lines could not be seen; and when too low the eye was unable to resolve the details.

The Literature. So far as the writer has been able to ascertain, the above factors have not been emphasized in the literature. The polarization of diffracted beams has, however, been studied by many physicists,[2] but the

[2] F. Arago. Oeuvres Compl. I, 431. 1813; G. Stokes. Trans. Cambr. Phil. Soc. *9*, 1. 1850; Phil. Mag. (4) *13*, 158. 1857; A. Rowland. Phil. Mag. (5) *17*, 413. 1884; S. Fröhlich. Wied. Ann. *1*, 321. 1887; *3*, 376, 568. 1878; *5*, 134. 1878; *6*, 414. 1879; *8*, 670. 1879; *13*, 133. 1881; *15*, 576. 1882; *22*, 161. 1884; M. Rethy. Wied. Ann. *11*, 504. 1880; W. Koenig, Wied. Ann. *17*, 1016. 1882; R. T. Glazebrook. Proc. Cambr. Phil. Soc. *5*, 254. 1885; H. Fizeau. Pogg. Ann. *116*, 478, 562. 1852; K. Exner. Wien. Sitzungsber. (11) *99*, 758. 1890; (11) *101*, 135. 1892; G. Quincke. Pogg. Ann. *149*, 273. 1873; Gött. Nachr. 1873, p. 22; Wied. Ann. *47*, 765. 1892; E. Du Bois. Wied. Ann. *46*, 552. 1892; H. Ambronn. Wied. Ann. *48*, 717. 1893.

application of the phenomena to the resolving power of the microscope seems not to have been done. The general theory of the polarization of diffracted beams for limiting cases such as above considered appears also not to have been worked out in detail. The phenomena are, however, easily observed and merit further investigation, especially from a theoretical standpoint.

SUMMARY

In the above paragraphs attention is directed to three factors which are of importance in high power microscope work, namely, (a) the use of a polarizing prism to eliminate that part of the field light which does not contribute to the diffraction pattern in the image and hence tends to reduce the contrast and to decrease the sharpness and crispness of the image. This phenomenon arises because diffracted beams which emerge from gratings whose interval is of the order of magnitude of half a wave length of light are sensibly polarized in a plane normal to the lines of the grating. (b) A diaphragm of the rectangular type is recommended for use in the image plane of the eyepiece in order to cut out all light except that from the particular object under examination. This device allows the eye to work at best efficiency because it is not disturbed by extraneous light. For the same reason the writer uses a soft rubber eye shield fitted to the microscope to cut out extraneous light from the sides. Rubber eyeshields of this kind have been employed by the Army and Navy for many years on fire-control and other observing instruments. A dark screen or curtain of velvet is also suspended between the observer and the strong source of light and shields his eyes from the intense rays which fatigue them quickly. (c) The importance of a field intensity of illumination approaching that of daylight and best adapted for the eye at any particular time is emphasized; the simplest method for securing this is by means of a substage polarizer in conjunction with the polarizing prism; the polarizer can be rotated and with it the intensity of illumination of the field varied.

These factors are not important for ordinary observations because the resolving power there required is not great; but in high-power, critical work they are significant and enable the observer to accomplish with comparative ease that which under other conditions is a matter of difficulty.

Following a clue given me by Mr. J. B. Wintringham, of Brooklyn, N. Y., since this paper was set up in type, I find that the use of a polarizing prism for "intensifying the resolving power of microscope objectives" was described in 1887 by G. D. Hirst in the *English Mechanic and World of Science* (Vol. 46, p. 232). The method was discovered first by Mr. Francis, of Sydney. Although Mr. Hirst describes the phenomena observed, neither he nor Mr. E. M. Nelson (p. 254 of the same volume) attempts to explain them, and the method appears to have attracted no further notice.

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THE FUTURE OF THE OPTICAL INDUSTRY IN THE U. S. A.[1]

SPECIAL RESEARCH APPARATUS

By P. V. Wells

It is a remarkable fact that the progress of man has almost always involved supplanting the other four senses by the sense of sight. Our consciousness is almost exclusively linked with nature through the optic nerve. Thus optical instruments have become the primary means of observation. To this everybody is witness. But this has long been especially true in science and technology. In the laboratories of specialists in physics, chemistry, metallurgy, geology, biology and medicine are found well-worn, much prized optical instruments. Excepting those treated by the other speakers, these are spectrometers, refractometers, spectroscopes, interferometers, polarimeters, petrographic microscopes, photometers, spectrophotometers, and many others.

As to the importance of such apparatus there is no doubt. But the demand is extremely limited, being confined to universities, to research institutions supported by the government, by large corporations, or by private endowment, to the small technical laboratories of industrial establishments, and to some few individuals. There is not a single one of these instruments with sufficient market to allow of the economy of quantity production.

Moreover these instruments require a very large amount of technical knowledge and highly developed skilled labor for their production. In the optical parts, in addition to corrected lenses and precision prisms, such special optical devices as Nicol and Wollaston prisms, biprisms, Lummer-Brodhun cubes, quartz plates and wedges, absorption screens, quarter wave plates, plane parallel plates, etc., require exact design and workmanship. The mechanical parts demand precision bearings, screws, divided circles, graduated scales, slits, etc., besides axial symmetry, rigidity, and precise adjustability. None of this work is beyond the demands of those precision instruments which have a more extensive market, but it is special, takes added time, and has not the sale to repay for the development required.

How is it possible to develop an industry under such adverse conditions? As a matter of fact the growth of this portion of optical industry has depended

[1] Presented before the Optical Society, December 27, 1918.

upon fortuitous circumstances. The invention and design has usually been the gift to posterity of philosophers and individual instrument makers. In each country a few select craftsmen have devoted a modest existence to what was largely its own recompense. The artistic productions of such men are of course priceless. It is only in recent years, however, that the powerful resources of competing industry have been turned upon such instruments, not directly for profit, but largely for the prestige thus acquired (one of the beneficial results of advertising). In this modern industry, the firm of Carl Zeiss in Jena has been pre-eminent.

The causes of this German semi-monopoly before the war are discovered without much difficulty. Chief among them was an overpopulation probably much greater than that of any European nation, to which may be added a rapid industrial expansion, particularly in the chemical industries, and a national appreciation of the relation of technology (or applied science) to industry. Cheap skilled labor, the recognition of the value of the technologist, national subsidy, and the advantages of reputation are the chief causes of the superiority of the German optical industry. It may also be remarked that the genius of the Zeiss-Abbe partnership, wisely nurtured in early days by the government, and perhaps also the advanced views of these two men on sociology, have contributed in no small measure to the special branch of optical industry we are considering.

It seems to be agreed upon by all that American industry, at least, should be independent, after the costly experience of this war. The question then arises, how are we going to make America independent in special research apparatus? I fear that such a feat is more easily desired than accomplished. Most certainly it will require the unstinted support of this Society.

One thing is certain, that if we are to become independent, someone must pay for it, because the conditions in this country are not favorable for competition with European industry, especially if it is assisted by the nations themselves. There are several sources of support which may be effective in developing the manufacture of research apparatus. These are (1) private benefaction, (2) the universities, (3) scientific and technical societies, (4) the industry itself, and (5) the government.

The nation as a whole suffered in the lives of its sons for its past neglect, and is therefore responsible. The government should therefore be the main source of assistance. A protective tariff is not very effective because

it does not apply to the universities or to the government, and because research apparatus is not purchased on the basis of price. Besides every effort should be made to stimulate research, not to choke it. A better method of government support is by direct assistance to the manufacturer, by supplying technical information, and by bearing the cost of the development of new improved instruments.

The government, however, should not and cannot produce the result alone. The benefits of research apparatus accrue to all mankind and should be fostered by all. The industry itself derives benefit in the very process of its manufacture and should not be unable to see the forest because of the trees. The universities should cultivate a more cordial relation with the industry and view with favor not only research itself, but investigation of research apparatus, and co-operation in putting it into production. As an object of private benefaction, also, individuals gifted in developing apparatus should be considered as worthy of research grants as in other branches of science. And finally the Optical Society, by its policy, by its political influence, and above all by the enthusiasm of its members should advance its not least important, if least lucrative, branch of optical industry.

ABSTRACTS

ROCKETS AND ILLUMINATING SHELLS AS USED IN THE PRESENT WAR. A. Bergman, Trans. Ill. Eng. Soc., Vol. 13, pp. 219–231, June, 1918. Read to New York Section of the I. E. S., New York, April 11, 1918.

Rockets and illuminating shells function not only in revealing enemy movements, but in laying down light barrages behind which it is impossible for the enemy to see. Rockets are propelled as in common fireworks, but provided with silk parachutes to provide for their suspension during their time of burning, usually about half a minute. Those to be fired from a rifle are given a maximum range of about 200 yards, those from trench mortars about one mile, and from a field or naval gun, a range of about three to four miles. The different types and their characteristics are described in the paper. The material used is not described.

The usual form is a cylinder about two inches in diameter and two inches long, burning from ten to thirty-five seconds, with an average candlepower of from 100,000 to 300,000. The total illumination provided, in candle-power-seconds per cubic inch, is nearly constant, ranging from 450,000 to 500,000.

The results of tests made at Sandy Hook are given in the following table:

CANDLEPOWER AND TIME OF BURNING
Diameter of Illuminants 1.94 in. (4.92 cm)
Burning Surface 2.95 sq. in. (19 sq. cm)

No.	Total length of light, inches	Total burning time, seconds	Average candlepower	Burning time per inch, seconds[2] $\frac{A}{B}$	Cubic inches of composition[3] A x 2.95	Total candlepower, seconds B x C	Candlepower seconds per cu. in.[4] $\frac{F}{E}$
71	2.44	16	213,000	6.55	7.2	3,400,000	472,000
72	2.00	10	269,000	5.00	5.9	2,690,000	456,000
77	2.25	22.5	143,400	10.00	6.65	3,210,000	482,500
78	2.12	16	186,500	7.55	6.25	3,000,000	480,000
92	2.25	35	89,700	15.5	6.65	3,140,000	472,500
103	2.37	35	96,700	14.75	7	3,385,000	484,000
110	2.37	31	108,800	31.1	7	3,375,000	482,500
111	2.37	32	113,300	13.5	7	3,630,000	520,000
112	2.63	32	115,150	12.2	7.54	3,680,000	475,000
113	2.5	28	132,300	11.2	7.4	3,700,000	500,000

The candlepower remains nearly constant during the time of burning. The effective area illuminated is approximately 600 years in diameter. In relative cost, this illumination is not very much greater than that provided by ordinary gas or electric lamps.

REPORT OF THE COMMITTEE ON NOMENCLATURE AND STANDARDS. Illuminating Engineering Society, 1918. Presented at the 12th annual convention at New York, October, 1918.

This 1918 report of the committee is essentially a duplicate of previous reports, with the addition of recommended standard values for the mechanical equivalent of light and for the relative visibility of radiation.

Mechanical Equivalent of Light. As a standard value for the mechanical equivalent of light, the figure 0.0015 watt per lumen is recommended.

Visibility. The following values for visibility and for relative visibility (maximum visibility being taken as unity) are recommended:

Wave length $\mu\mu$	Visibility of radiation, average normal eye		Wave length $\mu\mu$	Visibility of radiation, average normal eye	
	Relative to that at 566 $\mu\mu$	Absolute (lumens per watt)		Relative to that at 556 $\mu\mu$	Absolute (lumens per watt)
400	0.0004	0.0000006	600	0.631	0.00095
10	.0012	.0000018	10	.503	.00075
20	.0040	.0000060	20	.380	.00057
30	.0116	.000017	30	.262	.00039
40	.023	.000034	40	.170	.00025
450	0.038	0.000057	650	0.103	0.000154
60	.060	.000090	60	.059	.000089
70	.091	.000136	70	.030	.000045
80	.139	.000208	80	.016	.000024
90	.208	.000312	90	.0081	.0000122
500	0.323	0.00048	700	0.0041	0.0000061
10	.484	.00073	10	.0021	.0000031
20	.670	.00100	20	.0010	.0000015
30	.836	.00125	30	.00052	.00000078
40	.942	.00142	40	.00025	.00000037
550	0.993	0.00149	750	0.00012	0.00000018
60	.996	.00149	60	.00006	.00000009
70	.952	.00143		.....	.....
80	.870	.00130	...	.....	.....
90	.757	.00114	...	.....	.....

ULTRA VIOLET BAND OF AMMONIA AND ITS OCCURRENCE IN THE SOLAR SPECTRUM. A. Fowler and C. C. L. Gregory, Roy. Soc., Proc. 94, pp. 470–471, July 1, 1918. A study of the ammonia band near λ 3360 has been made using the third order of a 10-ft. Roland concave grating. A copper arc in an atmosphere of ammonia was used as a source.

The band consists of a bright maximum about λ 3360, a secondary maximum at λ 3371, and a number of lines arranged in groups of three, extending to a considerable distance in both directions. All the brighter ammonia band lines coincide with lines of unknown origin in the sun, 140 such coincidences having been verified, thus leaving little doubt as to the existence of ammonia in the solar atmosphere.

WATER VAPOR BAND λ 3064 AND THE SOLAR SPECTRUM. A. Fowler, Roy. Soc. Proc. 94, pp. 472–474, July 1, 1918. Comparisons made between Grebe and Holtz wavelengths, checked by the author's own observations, and Rowland's table indicate clearly the existence of 150 lines of the water vapor band at λ 3064 in the sun. The total number of lines in Grebe and Holtz list is 257, of which 63 fall on stronger solar lines, making identification impossible.

SPECTRUM OF LIGHTNING. J. B. Cannon, Roy. Astr. Soc., Canada J. 12, pp. 95–97, March, 1918. Two spectrograms made with a slitless spectrograph have been measured. Neovius' values of the wavelength of air lines were used as standards. The measures extend from λ 3893.2 to λ 5678.6. Results agree well with those given by Slipher.

FOCAL LENGTH OF 40-INCH YERKES TELESCOPE. E. E. Barnard, Astron. J. 31, p. 24, December 18, 1917. Professor Barnard gives the following data for 50° F.:

Distance from front surface of crown lens to focal plane..... = 746.7 inches
Distance from center of space between lenses to focal plane..... = 739.9 inches
Actual focal distance, by star measures..... = 762.0 inches

Hence the actual focal distance must be measured from a point situated 15.3 inches outside the surface of the crown lens.

INTRINSIC BRIGHTNESS OF STARLIGHT. H. Bourget, Comptes Rendus 166, pp. 943–945, June 10, 1918. A 6.5 cm. diameter camera lens, relative aperture F 7, forms an image of a portion of the sky on a diaphragm having an opening one centimeter in diameter. The camera lens as seen through this aperture is focused on a photographic plate by means of a microscope objective so placed that the diameter of the image is 1 mm. A three-minute exposure gives an image of suitable density. For comparison, the region of the sky immediately surrounding ϵ Ursae Minoris, and including this fifth magnitude star is also impressed on each photograph, using exposures of 3, 4 and 5 minutes in order to form a scale of densities.

Several regions of the milky way, and outside of this have been studied; the results show that the sky in the milky way is 1.7 times as bright as the sky outside.

BRIGHTNESS OF THE BLACK BODY AND THE MECHANICAL EQUIVALENT OF LIGHT. G. Holst and J. S. de Visser, K. Akad, Amsterdam. Proc. 20, 7, pp. 1036–1042, 1918.

The authors have determined the brightness of the interior of a heated enclosure kept at the melting point of gold. The work was done with intensities so high, that the Perkinje-effect was eliminated. The brightness obtained was 0.119 hefner (0.106 candle) per square cm. From the calculated emission of energy of a black body at 1336° abs., the above result gives 51.7 hefner (46.7 candle) per watt. This is in fair agreement with the value of 49.1 candles per watt obtained by Coblentz and Emerson (B. Stand. Paper No. 305, 1917).

THE VISIBILITY OF RADIATION. E. P. Hyde, W. E. Forsythe and F. E. Cady, J. Frank. Inst., June, 1918, Astrophysical Journal, Sept., 1918. A fresh set of determinations by 29 observers has been made at the Nela Research Laboratory by the step by step method. In Table I is given a summary of previous data obtained by various methods, together with the fresh data obtained by the authors. This latter includes the data previously published, obtained by Hyde and Forsythe at the red end of the spectrum and that of Hartman for the blue end.

TABLE I
Data on Relative Visibility

Wave lengths	Hyde, Forsythe, Cady	Ives, Kingsbury	Nutting	Coblentz, Emerson	Reeves
0.50	0.328	0.318	0.314	0.316	0.275
.51	.515	.473	.456	.503	.474
.52	.698	.637	.646	.710	.686
.53	.747	.801	.815	.862	.841
.54	.968	.915	.925	.954	.935
.55	.996	.988	.986	.994	.993
.56	.995	.996	.995	.998	.985
.57	.944	.947	.949	.968	.935
.58	.855	.859	.871	.898	.836
.59	.735	.758	.762	.800	.710
.60	.600	.653	.634	.687	.580
.61	.464	.534	.498	.557	.446
.62	.341	.396	.368	.427	.319
.63	.238	.283	.268	.302	.214
.64	.154	.183	.166	.194	.140
.65	.095	.110	.105	.115	.....
.66	.052	.068	.058	.064	.....

In Table II, are given values recommended by these authors for general use. It differs slightly from that recommended by the 1918 committee on nomenclature and the standards of the Illuminating Engineering Society.

TABLE II
Relative Visibility Data for Entire Spectrum

Wave length	Relative Visibility	Wave length	Relative Visibility	Wave length	Relative Visibility
0.40 μ	0.00009	0.52 μ	0.698	0.64 μ	0.154
.41	.00062	.53	.847	.65	.094
.42	.0041	.54	.968	.66	.051
.43	.0115	.55	.996	.67	.026
.44	.022	.56	.995	.68	.0125
.45	.036	.57	.944	.69	.0062
.46	.055	.58	.855	.70	.0031
.47	.087	.59	.735	.71	.0015
.48	.138	.60	.600	.72	.00074
.49	.216	.61	.464	.73	.00036
.50	.328	.62	.341	.74	.00018
.51	.515	.63	.238	.75	.00009
.....	.....	.....	.....	.76	.00005

RADIAL VELOCITY DETERMINATIONS WITH OBJECTIVE PRISM. M. Hamy, Comptes Rendus 167, pp. 9–12, 1918. The author has formerly described an instrument consisting of a telescope, objective prism, and a collimator to furnish the comparison spectrum. In this form it was essential to be able to measure accurately the angles of incidence of both star and comparison light.

A new plan is now proposed, consisting of two prisms exactly alike with their bases facing each other. Each is furnished with a telescope, the two telescopes making an angle with each other equal to twice the deviation of one prism. The entire spectrograph thus forms a system which is very rigid in the direction of the dispersion, so that it can safely be pointed towards a fixed collimator for impressing the comparison spectrum after the exposure to the star has been made. An observing telescope is rigidly attached to the prism system for insuring approximate equality of the angles of incidence; it is, however, obvious that the displacement of comparison spectrum with respect to stellar spectrum due to a change in angle of incidence will be in opposite directions on the two spectrograms taken simultaneously, hence an accurate knowledge of the angle of incidence is not important.

DIFFRACTION OF SOLAR IMAGES. M. Hamy, Comptes Rendus 166, p. 240, 1918; 166, p. 878, 1918. An accurate determination of the solar diameter is difficult on account of the great intensity of the light. If this is reduced by reducing the aperture, there is a great loss in definition; while if it is reduced at the eyepiece by any of the usual devices, other difficulties appear, most important of which are the temperature changes in the instrument itself produced by the powerful light or heat of the sun.

The author proposes to use in front of the objective, a slit whose length is equal to the diameter of the objective, and whose width can be varied so as to keep the amount of light admitted suitable for comfortable observation. The diameter to be measured is of course the one parallel to the slit.

The distribution of light in the image along this diameter has been investigated mathematically and the results show that the definition of the sun's limbs is even better than when no slit is used. A subsequent investigation (p. 878, et seq.) relates to the effect of shading the central portion of the slit, this having been found by Lord Rayleigh to improve the definition in the case of a circular aperture. In the present case, however, covering any portion near the middle of the slit results in loss of definition.

NEW STELLAR PHOTOMETER. M. Maggini, Comptes Rendus 166, pp. 284–286, February 18, 1918. A plate of plane parallel optical glass is placed in front of the eyepiece, its surface being inclined 45° to the axis of the telescope. On this plate is a circular piece of silver, a fraction of a millimeter in diameter, this being placed in the focal plane of the eyepiece. This tiny silver mirror receives illumination from a system consisting of a lamp focused on a small aperture in an opaque screen, which in turn is sharply focused on the silver mirror—the axis of this illuminating system being at right angles to the axis of the telescope. The observer on looking through the eyepiece will see in the middle of the field of view a small circular patch of light, the intensity and color of which may be varied at will by adjusting the brightness of the lamp, or by the use of suitable screens with the illuminating system.

The extra-focal image of a star is so placed that the small mirror will be seen near its center, this image itself being of course larger than the mirror- a setting is made by varying the size of the extra; focal image until the brightness of the mirror exactly matches that of the star. The distance "d" from the focal plane of the telescope objective to the focal plane of the eyepiece is then read. For another star, let this distance be "d_1." Then the difference in magnitude between the two stars is obviously

$$\Delta\, m = 5 \log \left(\frac{d_2}{d_1}\right).$$

By using a plate of colored glass and a color screen in the illuminating system comparisons may be made for different portions of the spectrum. The author has also worked without the silver mirror, merely reflecting the comparison light from the front face of the glass plate. By this means it has been possible to reduce the apparent size of the comparison disc to about 10 seconds of arc.

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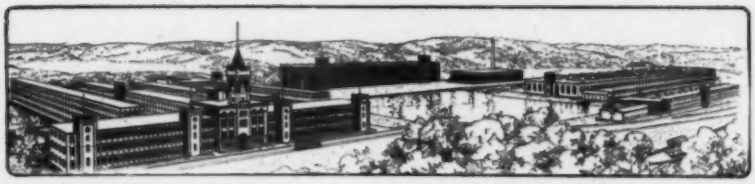

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Out of the conviction that, while there is individual ability in optical lines in this country second to none, there is marked need of organization and cooperation, the Optical Society of America was born.

Its purpose is to serve the interests of all who are engaged in any branch of optics, from fundamental research to the manufacture of optical goods. It is believed that it will attract the interest of:

> Astronomers who are interested in highly corrected instruments and the laws of vision and photography; Chemists in refractometry, colorimetry and polarimetry; Illuminating Engineers in photometry, light standards, diffusion and the laws of vision; Mineralogists and Petrographers in polarimetry and microscopy; Manufacturers of optical goods in the design, use and testing of lenses and optical instruments and in optical glass and refractometry; Various Manufacturers in the theory of color and the laws of colorimetric analysis and synthesis; Opticians, Optometrists and Opthalmologists in refractometry and the laws of optics and of photographic sensitometry; Teachers and Investigators of fundamental optical problems in the nature and uses of light and in the optical properties of materials.

The society proposes to realize its aims through conventions for the presentation of papers and exhibition of new apparatus and through the medium of this journal.

The constitution provides that anyone who has contributed materially to the advancement of optics shall be eligible to regular membership in the society with the privilege of voting and holding office. Anyone interested in optics is eligible to associate membership. Blank applications for membership and copies of the constitution may be obtained from the secretary.

Annual dues, including subscription to the JOURNAL, are five dollars.